DEVELOPMENT AND EVALUATION OF A DRIVER AIR BAG SYSTEM FOR THE CALSPAN RESEARCH SAFETY VEHICLE

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Final Report

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16. Abstract

A driver air bag system that can provide protection under small car high speed frontal impact conditions was designed, tested and evaluated in this program.

The vehicle chosen for the restraint integration process was the Calspan Research Safety Vehicle. Design constraints were timeliness, cost efficiency, retainment of good steering properties, and producibility. Results indicate that the restraint system developed appears capable of providing protection from fatality or serious injury to adult size drivers up through the 40 to 45 mph impact speed range.

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FOREWORD

This report presents the results of testing and analysis performed to design, develop, and evaluate a driver air bag restraint system for the Research Safety Vehicle (RSV). This study was performed by Calspan Corporation for the National Highway Traffic Safety Administration (NHTSA) under Contract No. DOT-HS-5-01214. The Contract Technical Manager was Franklin G. Richardson, DOT/NHTSA.

The opinions and findings expressed in this publication are those of the author and not necessarily those of the National Highway Traffic Safety Administration.

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The author is also indebted to Chrysler Corporation for their important inputs regarding feasibility of modifying the base vehicle steering components.

Lastly, the author would like to thank Franklin Richardson, NHTSA, for the cooperative and competent manner in which he carried out his responsibilities as Contract Technical Monitor.

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1.0 INTRODUCTION

The objective of the Research Safety Vehicle (RSV) program, which is being sponsored by the National Highway Traffic Safety Administration (NHTSA), is to provide research and test data applicable to automobile safety requirements for the mid-1980's. Reduction of highway accident losses, particularly human injuries and fatalities, is a major concern of the study. However, factors extending well beyond a strict consideration of safety are additionally being investigated. Namely, the compatibility of advanced safety requirements with efficient energy utilization, material resource conservation, environmental policies, and consumer economic considerations is being evaluated.

The Calspan/Chrysler approach to achievement of the above goals has been to start with an existing vehicle, the Simca 1307/1308, and upgrade it to meet advanced safety, fuel economy, and environmental requirements. In this manner, reasonable estimates of the effects of the upgrading process on vehicle producibility and cost could be obtained via incremental analyses.

The overall RSV program is being implemented in four distinct phases as outlined below:

PHASE I
- define program
- develop performance specification
- develop preliminary design

PHASE II
- perform system engineering and integration analysis
- develop total vehicle design
- test and evaluate vehicle subsystem designs

PHASE III
- refine and optimize design
- fabricate final test vehicles

PHASE IV
- test and evaluate vehicles

During the Phase I effort, both advanced belt and air bag restraints appeared to be equally promising candidate systems for integration into the RSV. Computer simulation studies and sled tests of idealized versions of these restraints were performed in Phase II. Based upon those and other inputs, it was concluded at the end of Phase II that advanced air belt restraints could provide somewhat superior impact performance than either a driver or passenger air bag. Refinement and optimization of the air belt therefore continued in the Phase III Calspan/Chrysler RSV program.

Because the RSV had the potential of offering the unique opportunity of investigating in detail the specific differences between advanced belt and bag designs (performance, weight, cost, structural requirements, etc.) when integrated into the same vehicle design, the NHTSA funded two additional parallel programs to develop production-oriented driver and passenger air bag systems. Another Contractor was given the task of designing and integrating a passenger bag into the RSV while Calspan Corporation was assigned the task of developing a driver air bag, the program reported herein.

It is noted that because of timeliness and cost effectiveness considerations, the approach for the development of the driver air bag system was based upon maximum use of existing hardware and devices. Significant modifications to the base vehicle steering system were discounted at the proposal stage because of the excessive cost implications for the Phase IV build cars. Since the base vehicle Simca steering wheel was not conducive to an air bag installation, direct replacement with a Volvo air cushion wheel was proposed at the onset of the program. Use of the Volvo GT steering wheel offered the following advantages: program timeliness, excellent non-deployed load distribution design which allowed wheel alignment with the chest on impact, and a built-in stowage provision for the driver air bag.

The end result of the Calspan effort was the development of a driver air bag system that could be integrated into the Phase IV Calspan/Chrysler RSV build vehicles. Figures 1-1 and 1-2 depict the final system that resulted from this program.

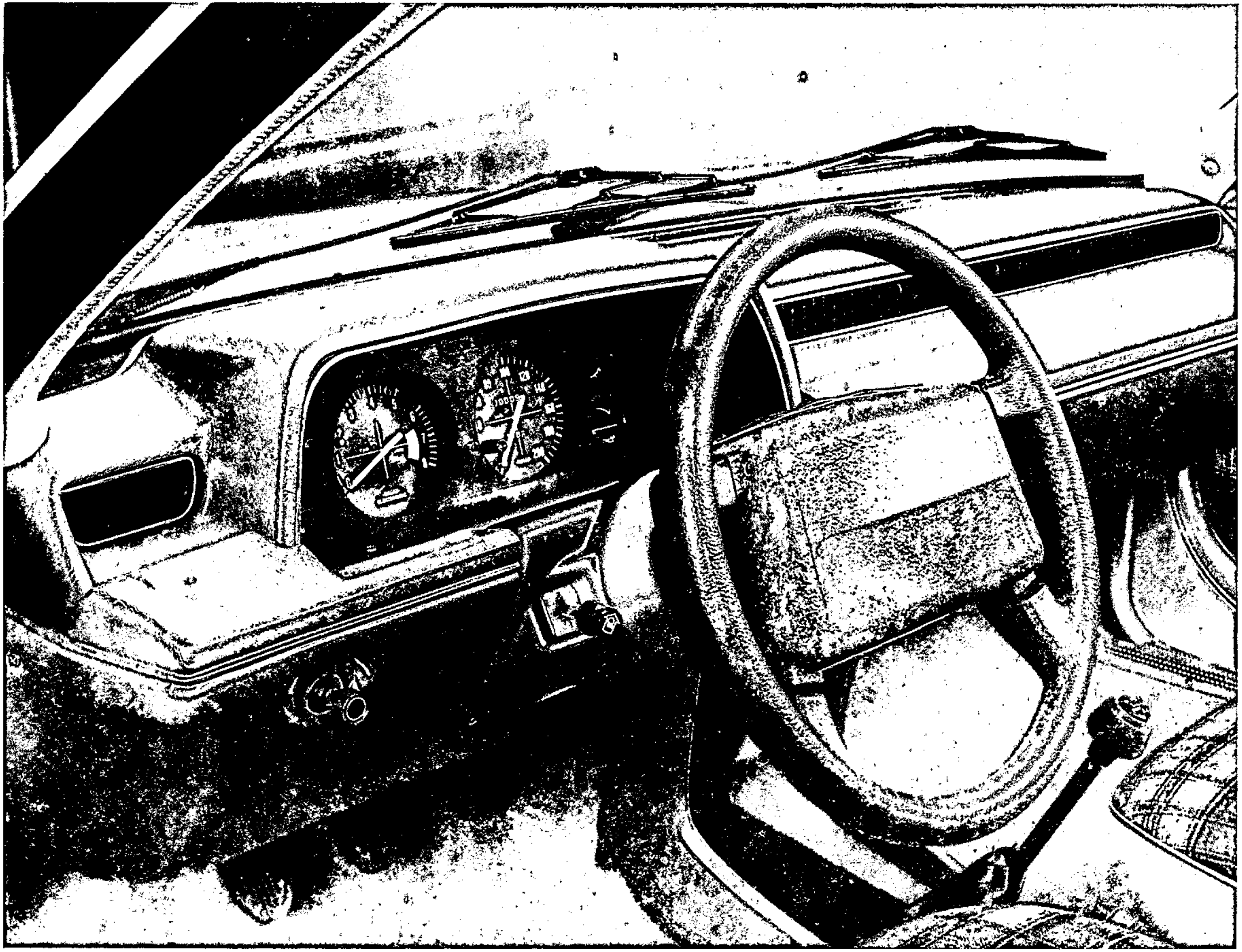


Figure 1-1   DRIVER AIR BAG FOR PHASE IV BUILD CARS

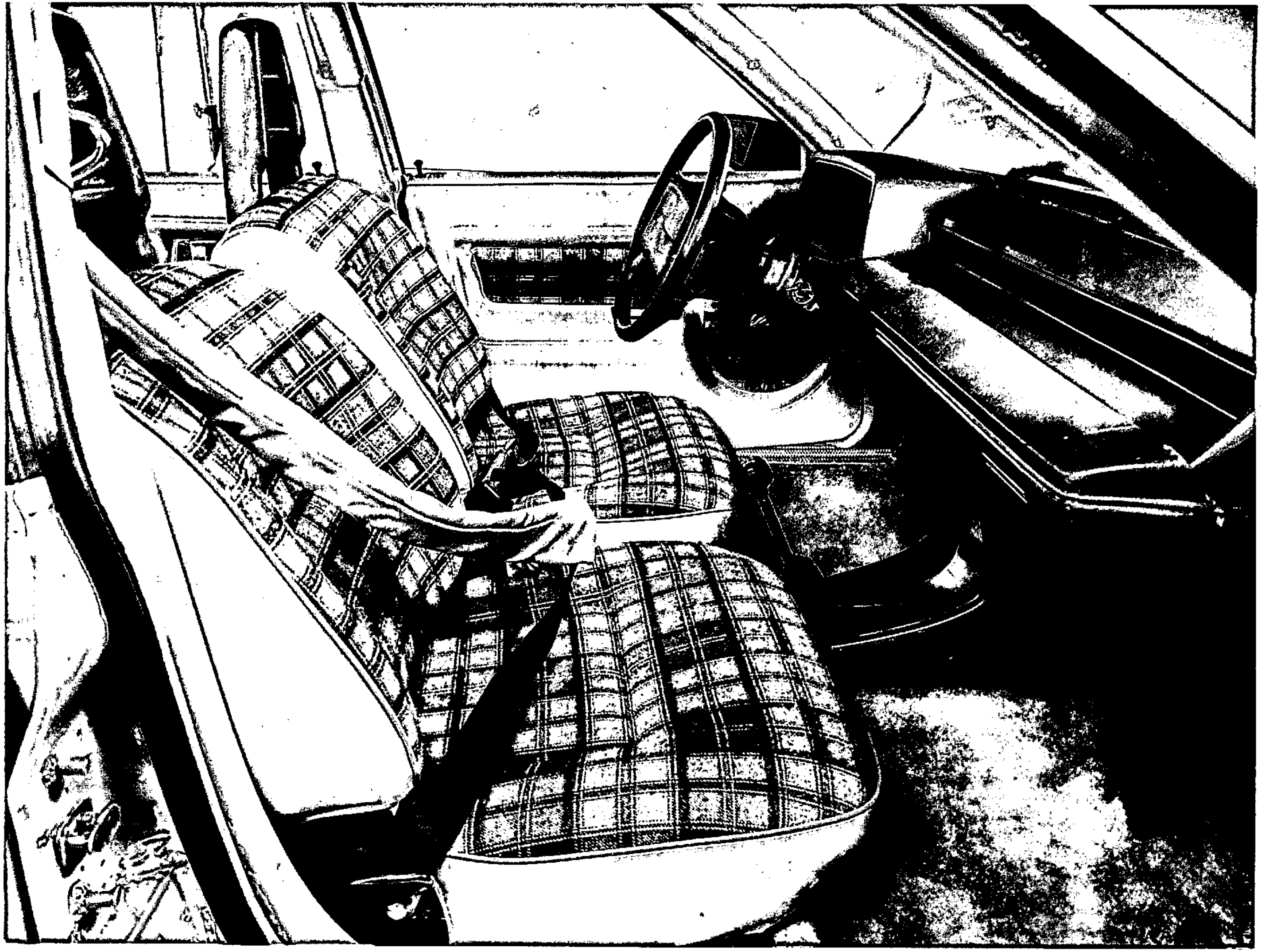


Figure 1-2 PHASE IV BUILD CAR INTERIOR WITH DRIVER AIR BAG

Initial effort on the driver air bag program was directed towards a review of the base vehicle steering system with respect to feasibility of modification to accept a driver air bag system. This was followed by component tests and computer simulations which were used to estimate potential occupant performance. The results of those efforts were then used to formulate a preliminary system design for the RSV. A series of developmental sled tests was subsequently performed to optimize the design. At the conclusion of the developmental sled testing, a final design was derived. That design was then evaluated in a series of sled tests which examined system sensitivity to parameters such as occupant size, impact speed, impact angle, seat position, and lap belt use.

It is noted that this program was completed prior to the conduct of the Phase III full scale evaluation tests. Phase II full scale test results and Phase III lumped mass-spring computer predictions were the only available data that could be used to generate a sled pulse design. Thus applicability of the sled test results was highly dependent on the subsequent correspondence between the predicted and resultant RSV front structure deceleration responses. Recently generated vehicle data indicates that the Phase IV RSV is significantly stiffer than had been anticipated. Instead of a maximum compartment acceleration of 40 g's at 45 MPH, values as high as 70 g's have been recorded. The results obtained from the present development program are valid for the compartment environment that was simulated. However, the conclusions should be tempered when these data are transferred to expected Phase IV RSV occupant performance because of the differences in anticipated and actual frontal crash responses for the vehicle.

Satisfaction of the current FMVSS 208 injury criteria for the 50th percentile male was demonstrated at 45 MPH for normal seated and off-design conditions (i.e., seat full forward, seat full rear, lap belt, +12°, $\pm 20°$). However, some concern has been expressed with regard to the method of achieving those results. Upward steering wheel shaft bending was the main energy dissipating mechanism. Repeatability of this process has been questioned. Furthermore, interaction of the lower steering wheel rim with the occupant's chest was seen to occur during the test event.

In order to address both of these concerns, steering column shaft bend angle data were analyzed and static tests were performed to assess the potential magnitude (force and chest compression) of the lower rim to chest interaction. Those data indicated that the shaft bending process is repeatable while the chest contact analysis was found to be inconclusive.

The ensuing sections of this report are organized according to the progression of work. Section 2.0 reviews the base vehicle steering system while Section 3.0 details the results of initial component tests and computer simulations. The developmental sled test results are reviewed in Section 4.0. At the end of the developmental sled testing a final design was obtained and results for that configuration are summarized in Section 5.0. The evaluation sled test program results are discussed in the subsequent Section 6.0. Section 7.0 concerns itself with the additional investigatory studies that were performed and, lastly, conclusions and recommendations for further actions are presented in Section 8.0.

2.0 REVIEW OF THE BASE VEHICLE STEERING SYSTEM AND DRIVER AIR BAG DEVELOPMENT PHILOSOPHY

Elements of the base vehicle steering column support structure are detailed in Figures 2-1 and 2-2. Important characteristics of the base vehicle steering configuration are the following:

- The base vehicle, Simca 1307/1308, has rack and pinion steering with the steering train ending forward of the firewall.
- A five inch offset exists between the toeboard hole to the rack and pinion and the steering column axis.
- Universal joints are present at the ends of the steering column and rack and pinion stub shaft.
- The clearance between the steering column end and the firewall is approximately eight inches.
- The steering column support pedestal is directly mounted to the top of the firewall structure. There is no support from the instrument panel.
- The spacing between the steering wheel and the instrument panel cluster is approximately eight inches.
- The Simca steering wheel is very soft from a force-deflection standpoint and has only two spokes (see Figure 2-3).

Review of the Simca 1307/1308 steering system with respect to integrating a driver air bag system into the RSV led to the following observations:

- The base vehicle steering wheel could not be adapted for a driver air bag installation: There was no provision for bag storage, and the upper rim of the wheel could not react air bag loads because it is so weakly supported. Direct substitution

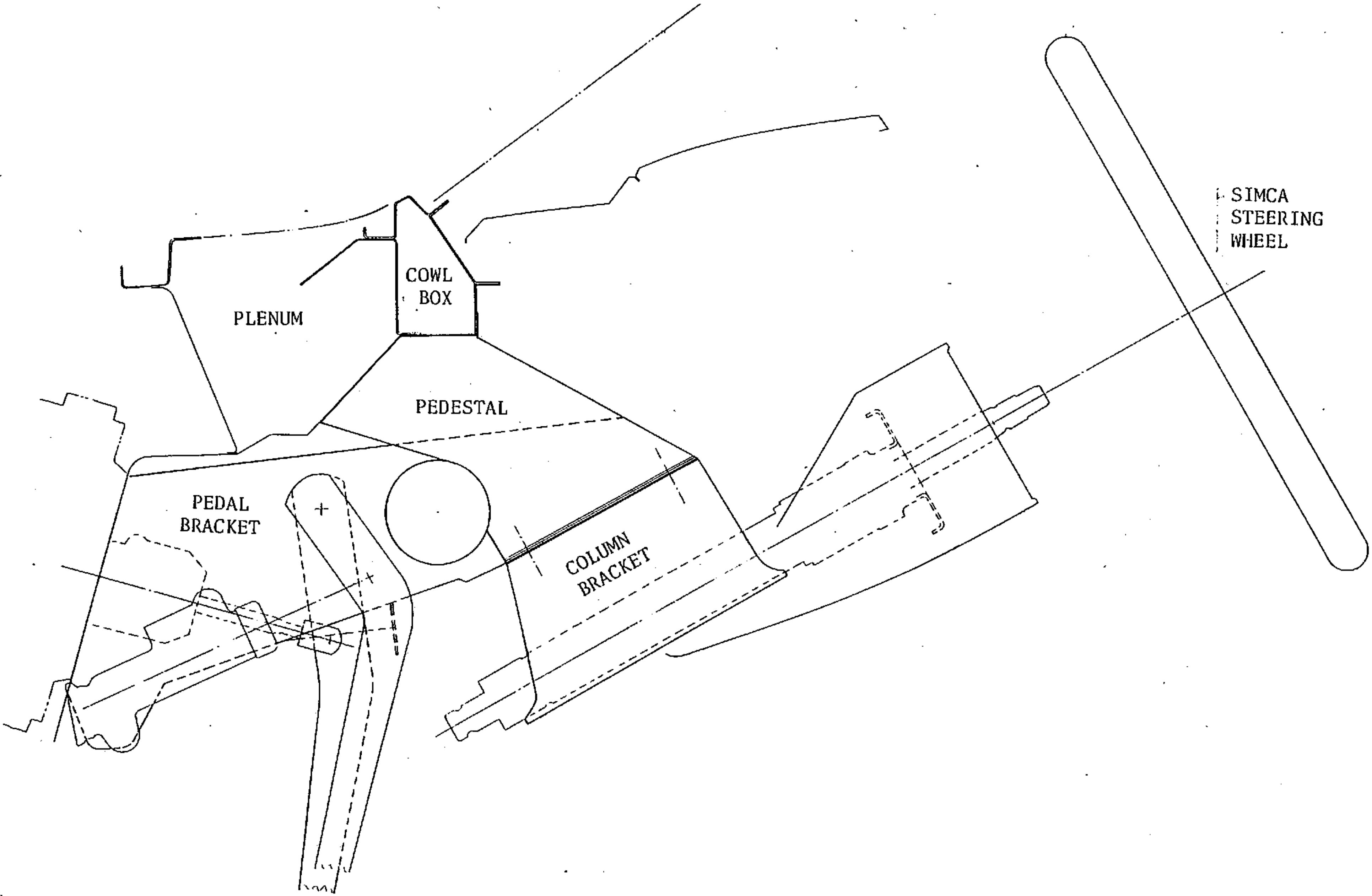
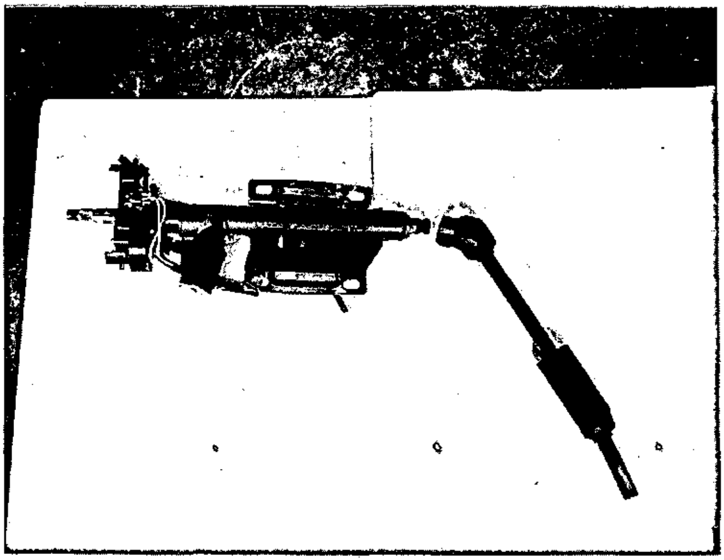
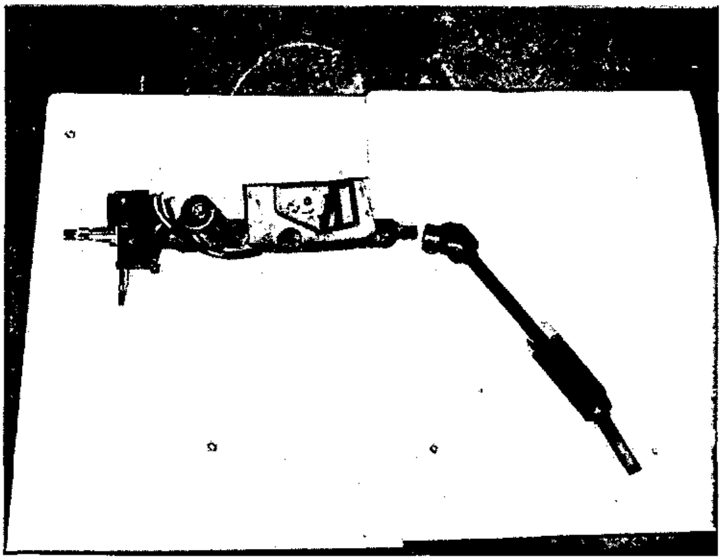


Figure 2-1   ELEMENTS OF THE BASE VEHICLE STEERING COLUMN SUPPORT STRUCTURE



VIEW FROM OVERHEAD



VIEW FROM INBOARD SIDE

Figure 2-2 SIMCA STEERING COLUMN ELEMENTS (APPEARANCE COVERS REMOVED)

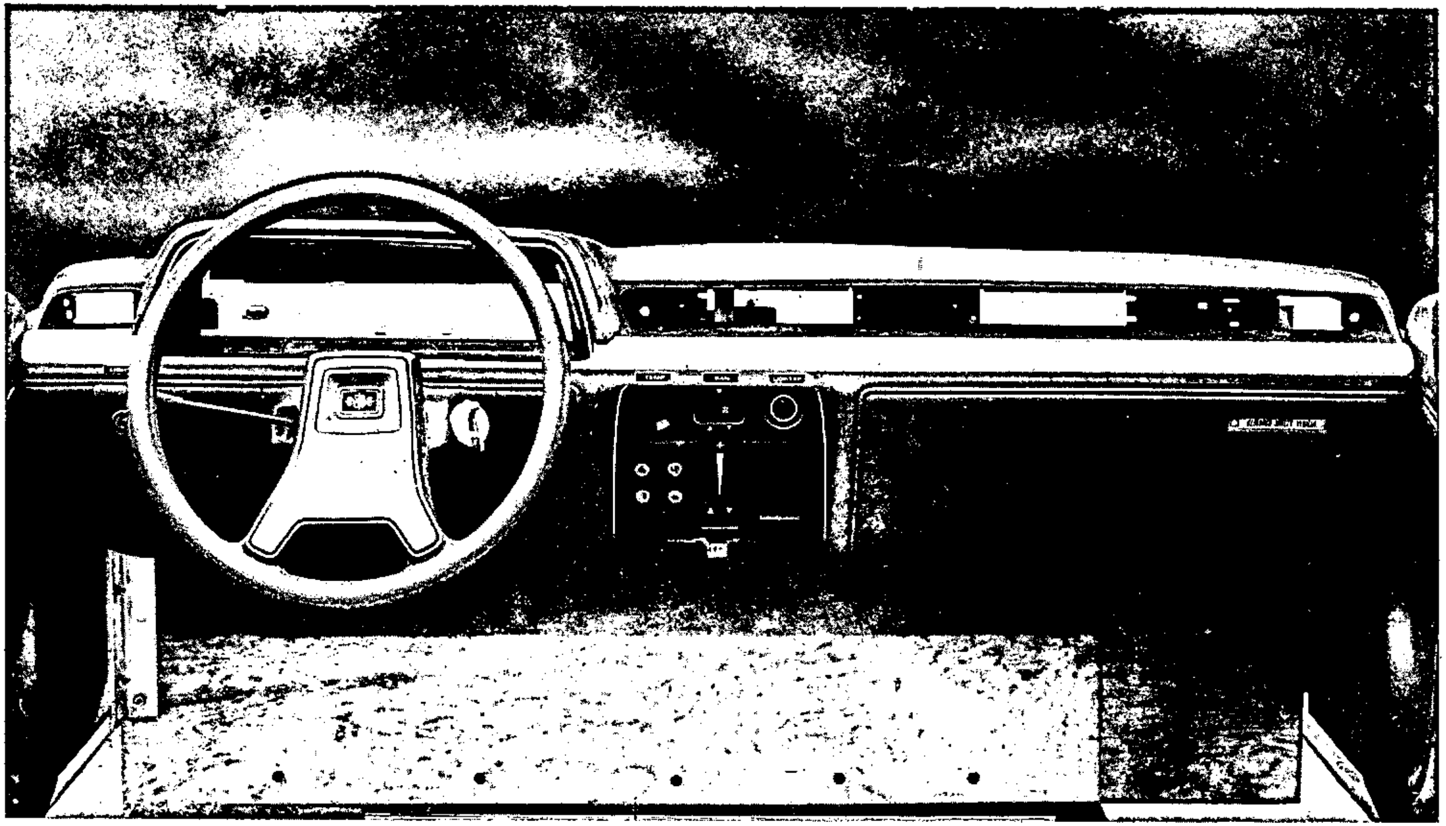


Figure 2-3 SIMCA STEERING WHEEL (IN A PHASE IV STYLING CLAY MOCKUP)

of the Volvo GT sport wheel was proposed at the onset because of the above deficiencies in the base wheel.

- There were no shear capsules for the Simca steering column and the column itself possessed no energy dissipation capability. The pedestal and pedal brackets could deform, however, to provide some energy dissipation.
- The pedestal bracket provided the primary support for the steering column. Since it was attached directly to the upper firewall area, local intrusions of that zone would be directly transmitted through the pedestal bracket and into the steering column.
- The steering column angle for the base vehicle was 28 1/2°. This was viewed as being fairly high. Some clearance in the column bracket was available to permit moderate column height and angle changes.

Once the base vehicle steering system was reviewed, meetings were held with Chrysler Corporation personnel to determine what modifications to the base vehicle steering system were feasible. Program constraints for those modifications were:

- Timeliness - the driver air bag development program was to be a ten month effort.
- Cost efficiency - retention of the existing column switch, wiring harness, and steering system elements forward of the toeboard. Also, the steering column configuration could not impact the instrument panel design for the driver air belt system.

- Attainment of good steering properties - This factor was best served by retaining, to the maximum extent possible, existing components.
- Producibility and deliverability - The final design had to be "reasonable" from an automotive design standpoint. This was not solely a research program; functional prototype parts suitable for installation in Phase IV vehicles had to be designed.

As a result of the feasibility discussions with Chrysler, a tentative design approach was formulated. Key items of that approach were:

- replacement of Simca wheel with the Volvo GT Sport Wheel
- utilization of the pedestal bracket for stroking and the installation of a collapsable element along the shaft axis to provide some "column" energy dissipation
- lowering the steering wheel column angle as much as possible.

Previous sled testing at Calspan, as part of the Aspirator Air Bag Program* had indicated that acceptable 40 mph impact performance could be obtained for the 50th percentile driver without column stroking. A Volvo GT sport wheel was used in those driver air bag sled tests; collapse of the wheel alone was sufficient to provide satisfactory results. By utilizing the limited stroking potential of the pedestal and installing a small crushable element along the steering column axis, such as an aluminum honeycomb cylinder, it was felt that 45 mph occupant performance could be obtained.

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*Contract No. DOT-HS-5-01254, Development of the Aspiration Inflation Technique for Compact Cars - Front Seat Passenger, Progress Report No. 17.

Chrysler indicated that a 5° angle reduction for the steering column was all that was feasible. The method of obtaining that change was not straightforward, however. As a first step, the base vehicle steering shaft and jacket were broken free from within the column bracket and rotated 5°. The Simca lower wheel rim position was used as the pivot point. This process caused the angles of the universal joints to exceed specifications. The entire shaft, jacket and wheel then had to be translated 1-1/2 inches rearward in the vehicle along the steering shaft axis so that the universal joints were within operating tolerances. At that point, the Simca wheel was replaced by the Volvo GT sport wheel. Both the translation of the steering wheel shaft along that shaft axis and the wheel replacement (Volvo wheel height was greater than that of the Simca) resulted in upward displacement of the lower wheel rim relative to the baseline position. Visibility of the instrument cluster was now obstructed. The assembly was therefore lowered 1/2 inches parallel to the new shaft axis (23-1/2°) so that the bottom of the Volvo wheel rim was very close to the original Simca wheel height. Figure 2-4 compares the positions of the baseline Simca wheel and the Volvo steering wheel after the angle change.

Once this preliminary design work was performed, computer simulations were performed to provide estimates of required bag properties and column collapse forces. Component tests were performed simultaneously to assess existing hardware performance.

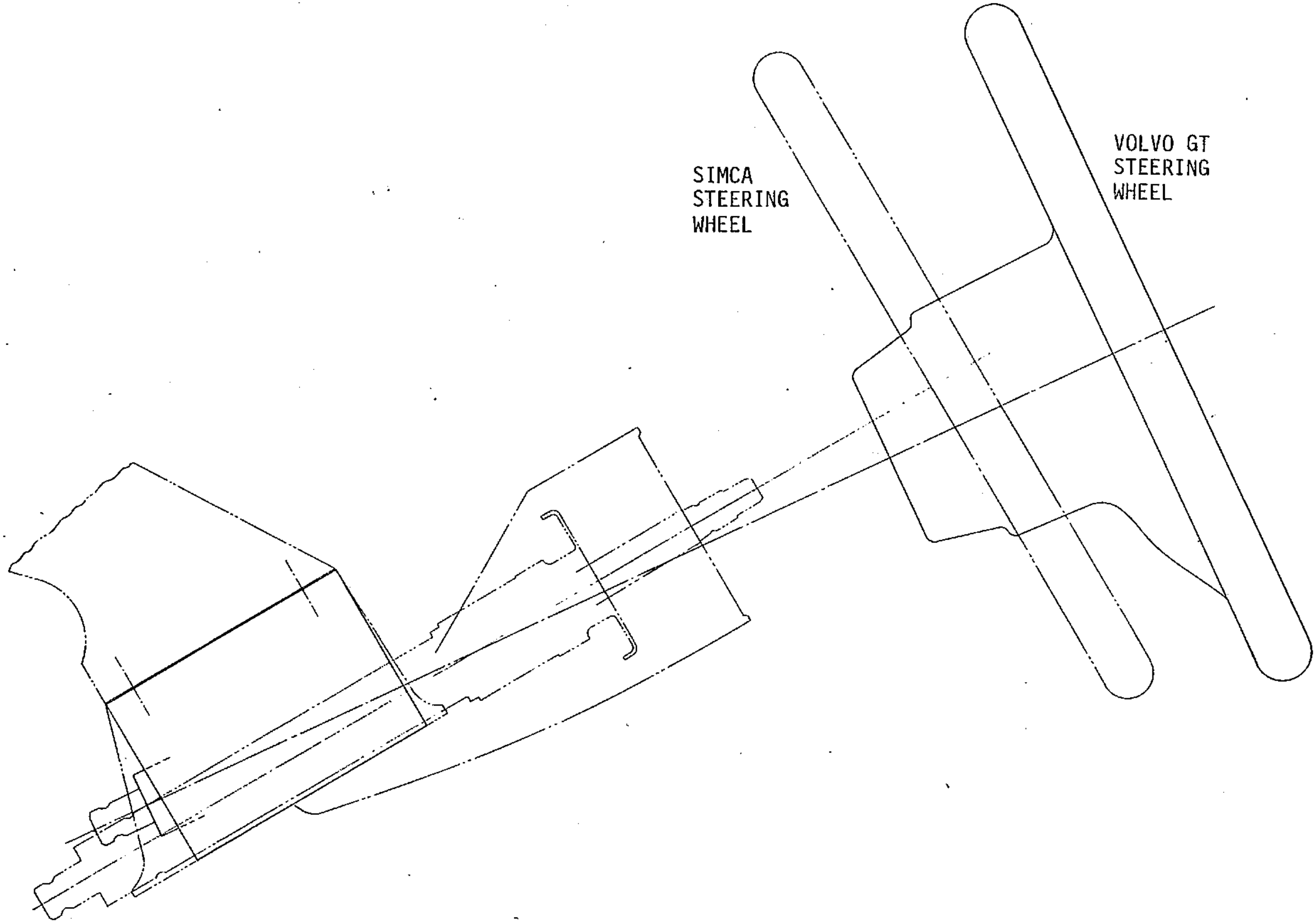

Figure 2-4 LOCATION OF VOLVO GT STEERING WHEEL AFTER MODIFICATION TO THE STEERING COLUMN ANGLE

3.0 COMPUTER SIMULATIONS AND COMPONENT TESTS PERFORMED PRIOR TO DEVELOPMENTAL SLED TESTING

This section details the preliminary effort expended to generate a baseline driver air bag restraint system for developmental sled testing. Computer simulations were used to provide acceptable performance bounds for the major restraint system components. Simultaneously, bench tests were performed with available "off the shelf" hardware to determine its suitability for use in the program. Specifically it was desirable to use a steering wheel like the Volvo GT sport wheel because the spoke configuration was adaptable to installation of a driver module. Furthermore, previous experience with Thiokol driver inflators showed them to be ideal candidates for integration into the system. No effort was expended on the development of a knee restraint because that was a direct carryover item from the Phase III air belt program.

3.1 ABAG 19 Computer Program

Simulations were conducted with the Calspan-developed ABAG 19 computer model to develop performance bounds for alternative RSV driver air bag restraint system components. The following paragraphs detail that effort.

Model Description

ABAG 19 is a one-dimensional computer program that predicts the deceleration response of a body block impacting a cylindrical air bag mounted on a collapsible collinear steering column. Design parameters that can be evaluated include bag size, gross bag shape, pressure inflow time history, venting, steering column force deflection properties, and the vehicle deceleration pulse. A pictorial representation of the model is presented in Figure 3-1. This is followed by a sample input format for the program (see Table 3-1).

System Variables

A large portion of the modeling focused upon determining the steering column stroke required for alternative driver air bag systems and occupant conditions. The system variables that were evaluated, and the corresponding values used, are detailed in Table 3-2.

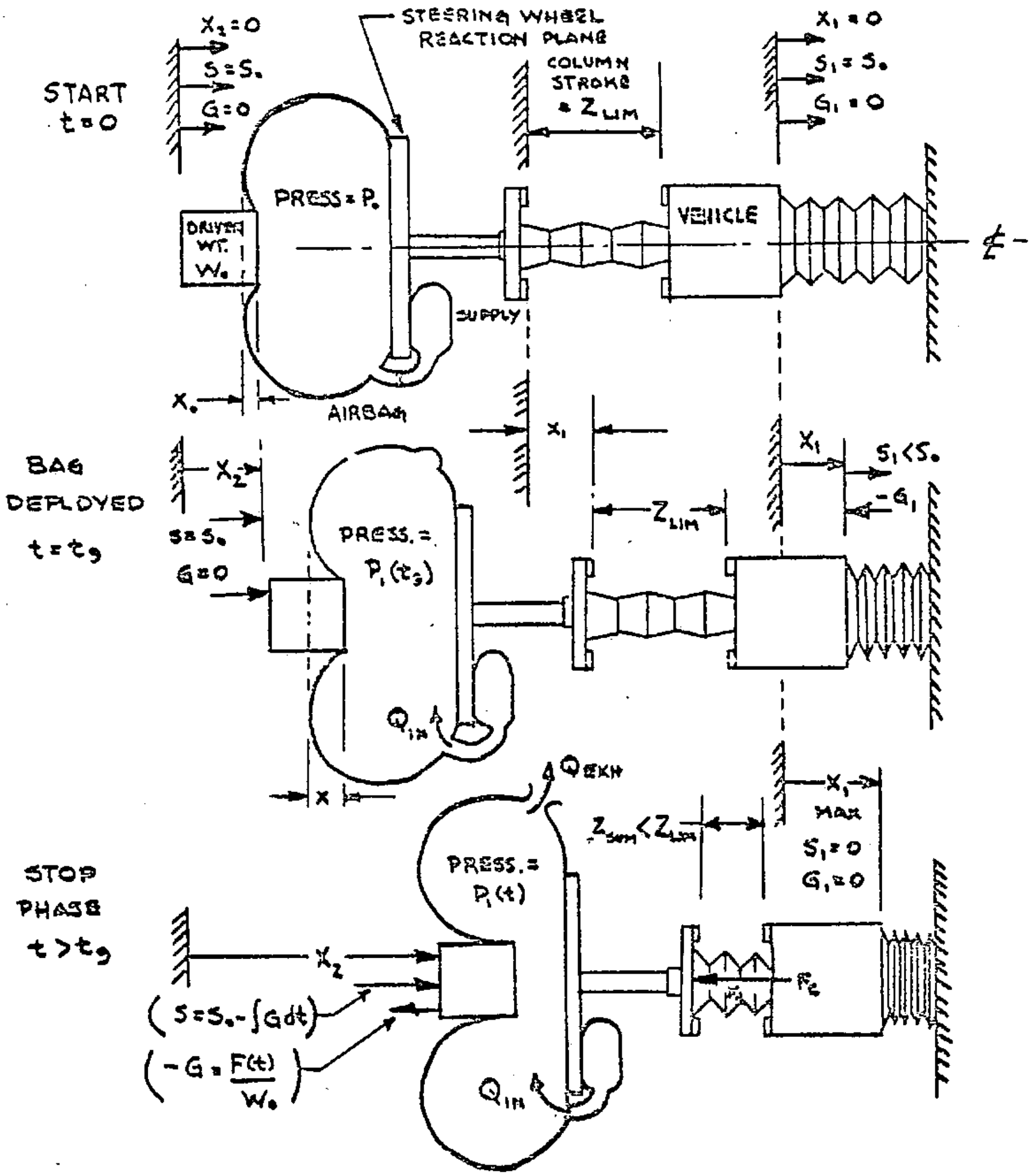

Figure 3-1 SCHEMATIC OF ABAG 19 COMPUTER PROGRAM

TABLE 3-1

TYPICAL ABAG 19 INPUT DATA

```
BAG DIAM= 13.7 INCHES          PERIPH= 32.7 INCHES
INITIAL BAG PENETRATION=  0.0 INCHES        DEPLOYED AT 0.0   SEC

BODY WIDTH= 13.0 INCHES     MASS= 75.0 LBS     VELOCITY= 67.5 FPS

VENT AREA= 5.0 SQ IN     OPENED AT: 0.1 PSIG
INITIAL PRESS= 0.0 PSIG     AT  370.0 DEG F

COL. FORCE= 4000.0 LB AT  0.3 IN FOR  9.8 IN ,**** LB AT 20.0 IN
COL. STROKE LIMIT= 30.0 INCHES

VENT DISCHARGE COEFFICIENTS:  VC1 , VC2          =  1.0  1.0
POLYTROPIC PROCESS EXPONENTS: PN1 , PN2 , PN3 =  1.4  1.4  1.4
UNIVERSAL GAS CONSTANT:  U=  640.0  (IN-LBS)/(LB-DEG R)
SOURCE GAS FLOW:  TQ(K)=  0.013  0.017  0.045  0.070  SEC
   K=1,4            Q(K)=  0.0    4.750  1.185  0.0    LBS/SEC

TIME + VEHICLE DECELERATION:  TGVD(N),GVD(N) , N=1,NG ; NG= 22
```

N	TIME SEC	GVD G UNITS
1	0.0	0.0
2	0.005	5.00
3	0.010	12.00
4	0.015	13.00
5	0.020	13.50
6	0.025	14.50
7	0.030	17.00
8	0.035	21.00
9	0.040	25.00
10	0.045	31.00
11	0.050	36.50
12	0.055	37.50
13	0.060	36.00
14	0.065	34.00
15	0.070	32.00
16	0.075	28.50
17	0.080	25.00
18	0.085	21.00
19	0.090	17.50
20	0.095	12.00
21	0.100	6.50
22	0.105	0.0

```
DELT= 0.0005 SEC     PERIPH ERR= 0.001       PRINT INTERVAL=  10
```

Table 3-2

SYSTEM VARIABLES EVALUATED

Variable	Values Used
Steering Column Collapse Force	1,500 lbs. 2,000 lbs. 2,500 lbs. 4,000 lbs. 10,000 lbs.
Static Bag Pressure	3 psig 5 psig
Separation Distance Occupant-Bag Deployment Point	14.7 inches 18.7 inches

Note that steering column stroke length was not limited. Furthermore, the column stroke length in these simulations would represent the total stroke in a physical experiment. This would be the sum of chest deflection, steering wheel crush and column stroke. In the RSV, the available stroke could be of the order of 3-5 inches even for a non-collapsible column due to a chest deflection of 1 to 2 inches and steering wheel crush of an additional 2 to 3 inches. All 20 possible combinations of the above values (see Table 3-2) were simulated for each of the following crash pulse and occupant environments:

Deceleration Waveform	Occupant Size
40 mph RSV sled pulse	5th percentile female 50th percentile male 95th percentile male
45 mph RSV sled pulse	50th percentile male
46 mph Volvo sled pulse	50th percentile male

The above runs were performed under conditions of constant bag size and venting. A preinflated 2.2 cubic foot bag with a diameter of 18.7 inches and a vent area of 5 square inches was employed. Selection of these fixed variables is discussed in the next section.

In addition to the aforementioned simulations, Volvo driver air bag data from the aspirator air bag program* were used for the purpose of validating the model.

Input Details

The analysis was simplified by using a preinflated bag. It was estimated that this would not affect the results significantly because of the short inflation times associated with driver bags** and the relatively small occupant displacements that occur during the first 20 milliseconds after vehicle impact.***

It is noted that the distance of a 50th percentile male torso to the hub of the RSV steering wheel is approximately 18 inches. The ABAG 19 program requires as a minimum that the bag touch the occupant. A bag diameter slightly larger than this was used (18.7 inches). Furthermore, a torso block width of 13 inches was used because this value is typical for all three adult occupant dummy sizes.

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*Development of the Aspiration Inflation Technique for Compact Cars - Front Seat Passenger, Progress Report No. 17, Contract No. DOT-HS-5-01254.

**For example, the Eaton X2623-04 Driver Module provides over 70% of its generated gas within 13 milliseconds after sensor closure.

***RSV occupant motion is typically less than one inch during the first 20 milliseconds of high speed runs.

The ABAG 19 air bag is modeled as a right circular cylinder with hemispherical end caps. The cylinder length must be equal to or greater than the torso block width. A value of 14 inches was employed. This results in a cylinder volume of 2.22 ft^3. The hemispherical end caps add an additional 1.97 ft^3 to the volume resulting in a total volume of 4.19 ft^3.

For the simulation, use of this larger bag volume results in a conservative estimate of required column stroke because (1) a narrower bag with the same diameter and at the same initial pressure would provide a slightly greater amount of ridedown due to the increased pressure buildup, and (2) decreasing the bag diameter would result in the occupant being closer to the steering wheel and that would also improve ridedown.

The other alternative was to reduce the width of the occupant. A 2.2 ft^3 bag with an 18.7 inch diameter would necessitate using an occupant torso block having a width of 1 inch. This latter approach is obviously unreasonable and thus was not employed.

Bag venting of 5 square inches was used. This represents the summation of approximately 2 square inches of port venting and 3 square inches simulating bag seam leakage.*

Also, the following effective weights were used for the driver torso:

5th percentile female - 50 lbs.
50th percentile female - 75 lbs.
95th percentile female - 100 lbs.

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*Phase II RSV simulation studies determined that for a 5 cubic foot passenger bag inflated to a static pressure of 4 psig, venting due to bag leakage was equivalent to approximately 5-6 square inches. It was assumed that the driver air bag would experience about half this amount of leakage.

Results

Because the RSV does not have a collapsible column, available stroke is severely limited. Even so, the ABAG 19 results indicate that with a stiff bag (5 psig) and a 4000 lb. steering column resistance, 40 mph protection can be achieved for all three occupant sizes; additionally, acceptable results can be obtained with the 50th percentile male at 45 mph. A cursory glance at the 5th percentile female data (see Figure 3-2) may seem to indicate that a 4000 lb. column collapse load is too stiff. However, since the female would be seated closer to the wheel than the 50th percentile male (≃ 2.5 inches closer), the 4 inch initial bag penetration curves are more representative. Those curves indicate acceptable performance even with a non-yielding totally stiff column (10,000 lb. collapse force). Data illustrating these results are presented in Figures 3-2 through 3-5. The data are arranged by deceleration pulse/occupant size combinations.

Validation of the ABAG 19 Computer Program

A series of sled tests was performed with Volvo driver air bag systems as part of the aspirator air bag program.* Data from that effort were used to validate the ABAG 19 program. In particular, sled tests 1640 and 1636, conducted at 46 and 42 mph, respectively, were modeled.

The Volvo driver system utilized a bag with an elliptical cross section having a depth of approximately 12 inches and height and width diameters of 24 inches. When deployed, the bag had a pitch angle of 22-1/2 degrees from vertical. An Eaton solid propellant gas generator was used to inflate the 2.1 cubic foot bag and a sensing time of 10 msec was simulated.

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*Development of the Aspirator Inflation Technique for Compact Cars - Front Seat Passenger, Progress Report No. 17, Contract No. DOT-HS-5-01254.

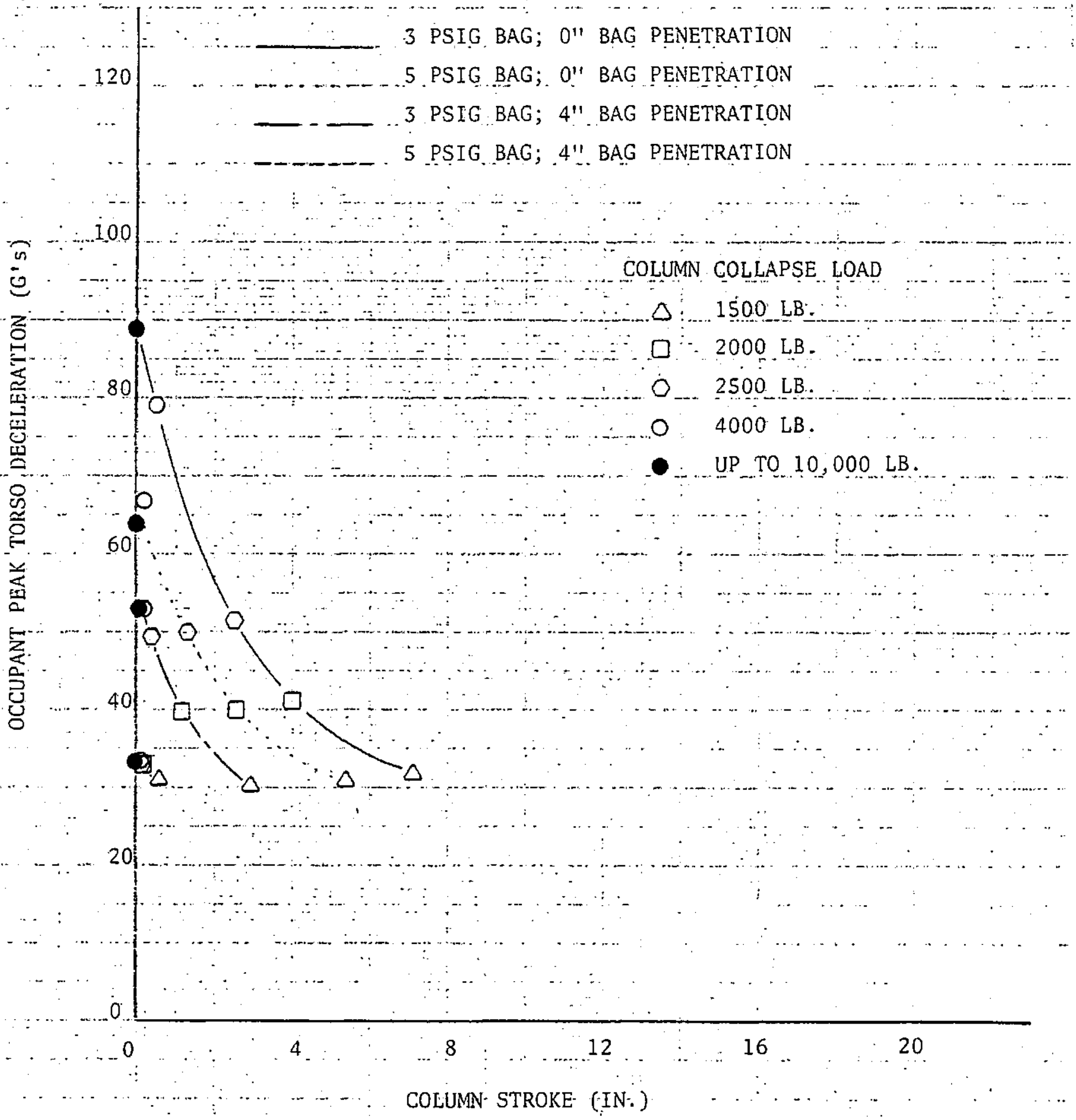


Figure 3-2 ABAG 19 COMPUTER SIMULATION RESULTS
5TH PERCENTILE FEMALE OCCUPANT
40 MPH RSV SLED DECELERATION PULSE

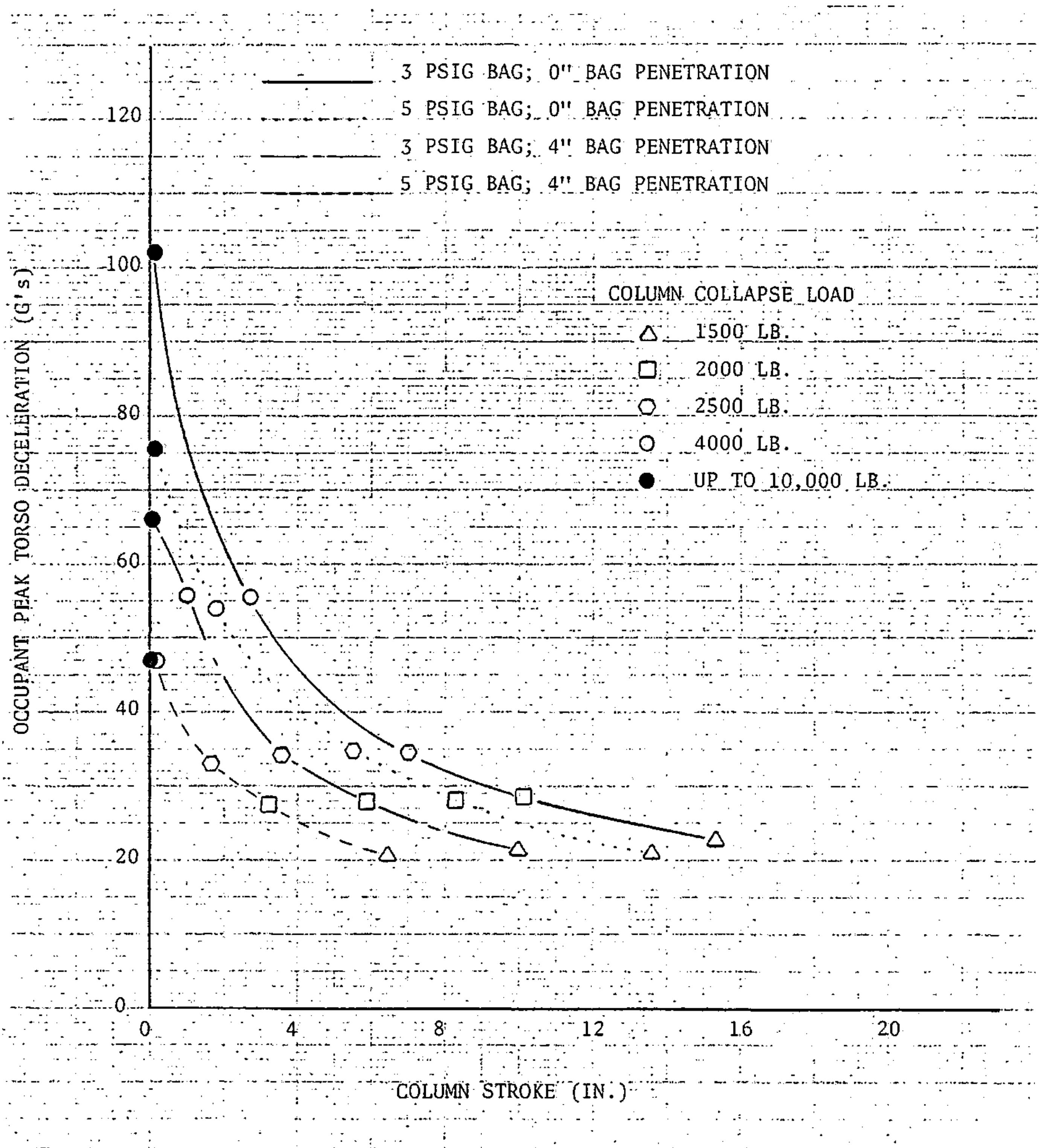


Figure 3-3 ABAG 19 COMPUTER SIMULATION RESULTS
50TH PERCENTILE MALE OCCUPANT
40 MPH RSV SLED DECELERATION PULSE

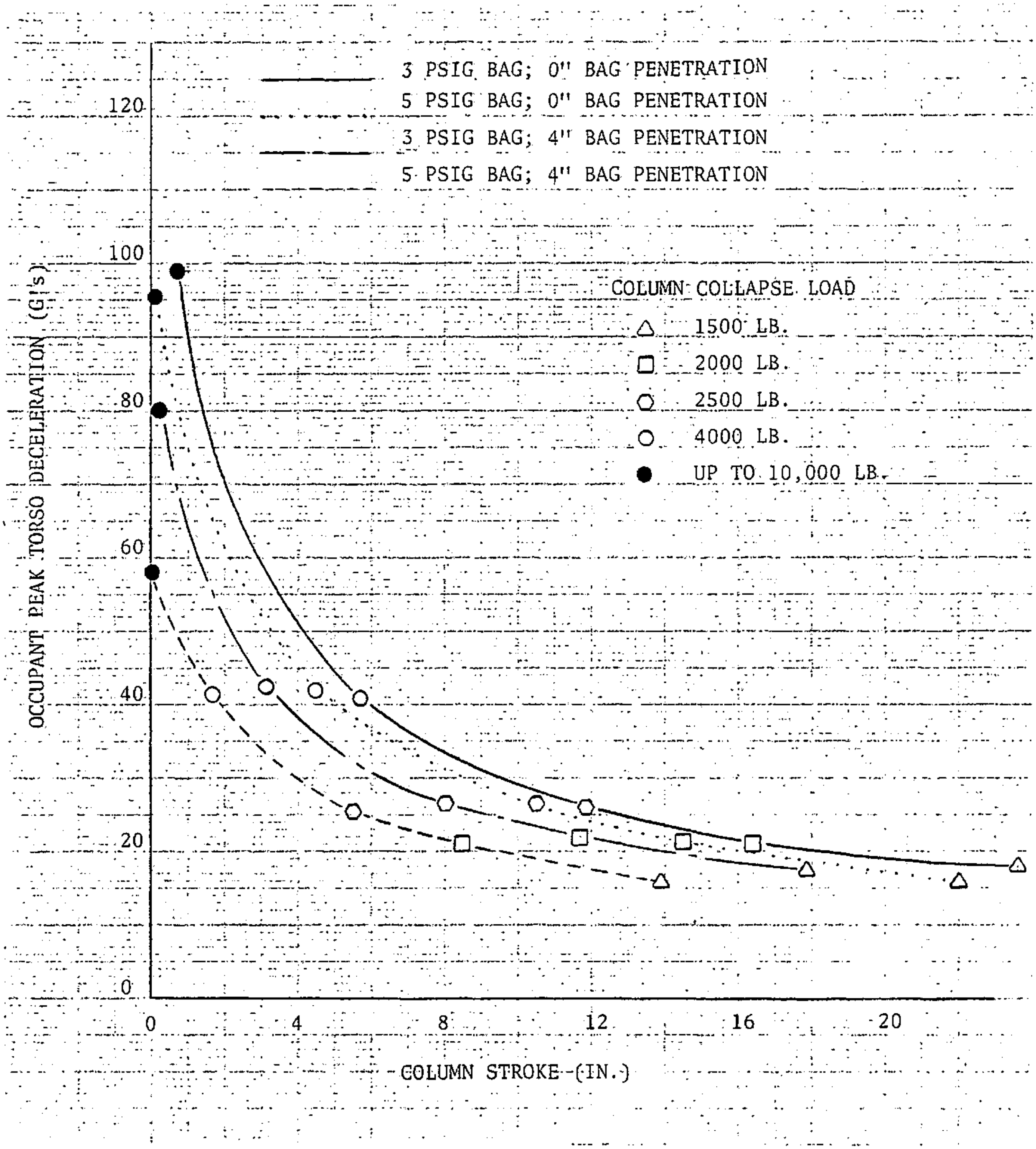


Figure 3-4 ABAG 19 COMPUTER SIMULATION RESULTS
95TH PERCENTILE MALE OCCUPANT
40 MPH RSV SLED DECELERATION PULSE

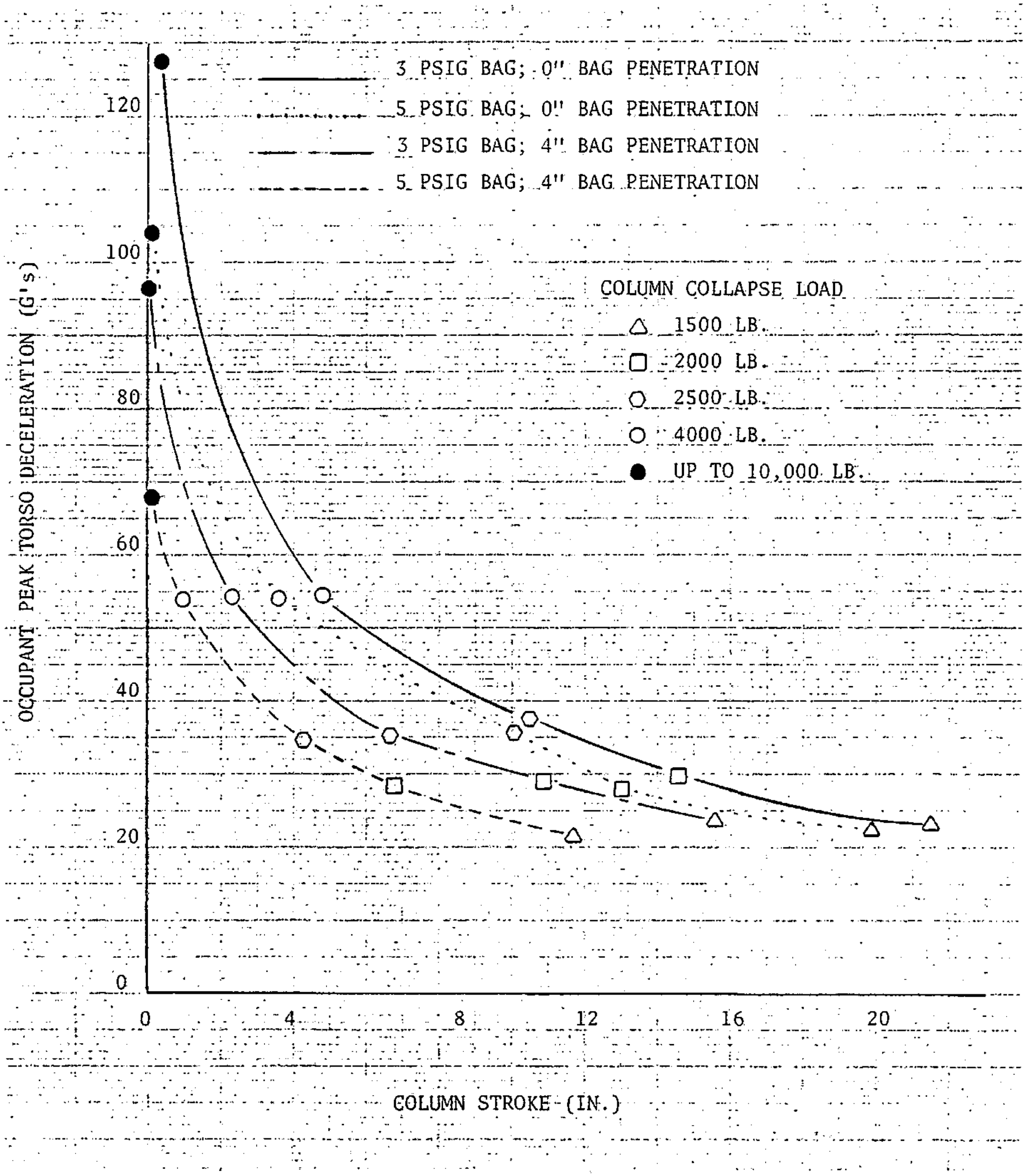


Figure 3-5 ABAG 19 COMPUTER SIMULATION RESULTS
50TH PERCENTILE MALE OCCUPANT
45 MPH RSV SLED DECELERATION PULSE

The ABAG 19 computer program can simulate only non-pitched circular cylinder bags with hemispherical end caps. The bag dimensions used in the previous ABAG 19 simulations were assumed; that is, an 18.7 inch diameter bag with a cylinder length of 14 inches because they reasonably approximated the overall Volvo dimensions. A comparison of the Volvo bag shape and its simulation is presented in Figure 3-6.

Since sufficient data were not available to completely describe the Eaton inflator, the gas flow rate of a similarly sized Thiokol unit was modeled. This input data is depicted in Figure 3-7.

Although the Volvo steering column was rigid for these sled tests, a collapse load of 4000 lbs. was input into the simulation because the column collapse force represents not only the steering column yield load but also the chest and steering wheel compliance. A complete input listing for the 46 mph Volvo sled test was shown in Table 3-1. Comparisons of the torso response and bag pressure time history for both the 46 and 42 mph sled runs are presented in Figures 3-8 and 3-9.

Very good correlation was demonstrated for the chest decelerations while the pressure time histories were overpredicted slightly. Use of a 4000 lb. collapse load for the steering column input resulted in peak torso accelerations that were reasonably close to actual test values. Furthermore, the time of initiation of occupant deceleration and the onset slope were very accurately predicted by the simulation. It should be noted that the onset timing and slope are independent of the column collapse characteristics. Thus, if a 10,000 lb. collapse load was simulated, the initial deceleration response would be identical to that of Figures 3-8 and 3-9 up to the point of constant force crushing of the column.

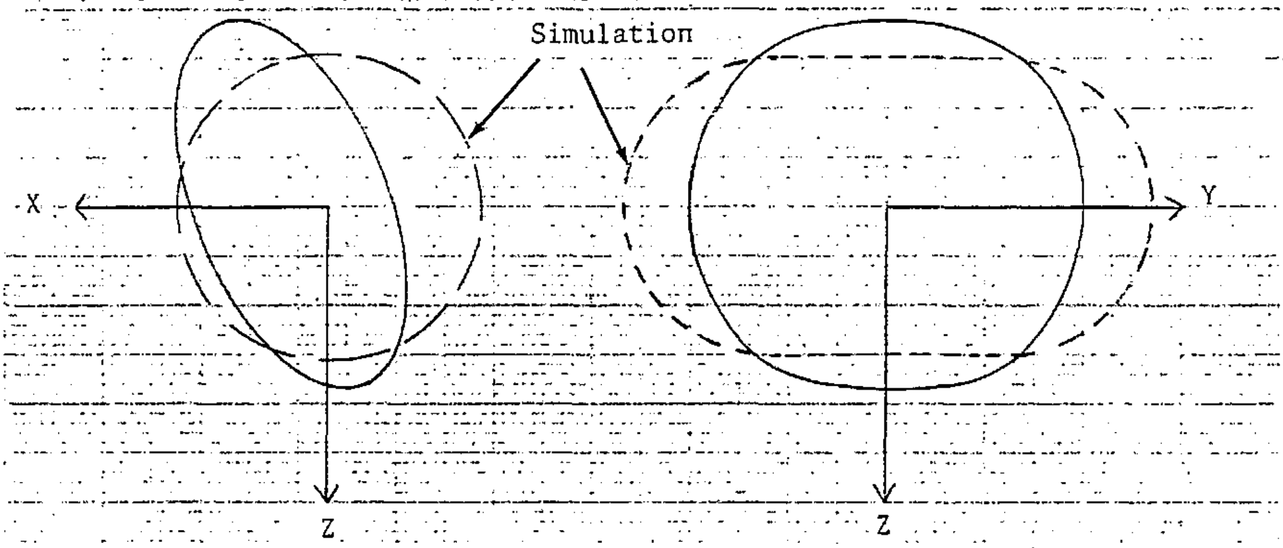


Figure 3-6 VOLVO DRIVER BAG SHAPE

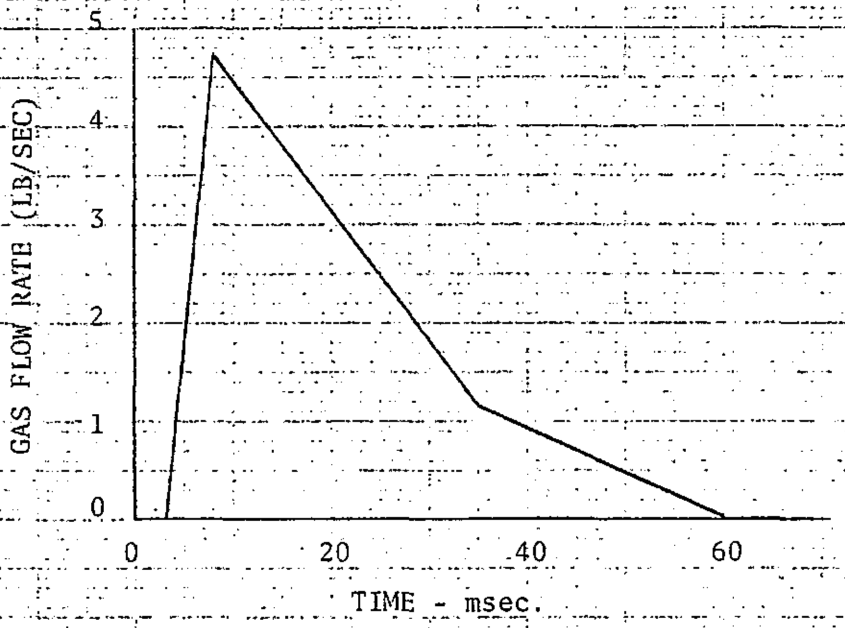


Figure 3-7 THIOKOL UPLOADED DRIVER INFLATOR PERFORMANCE

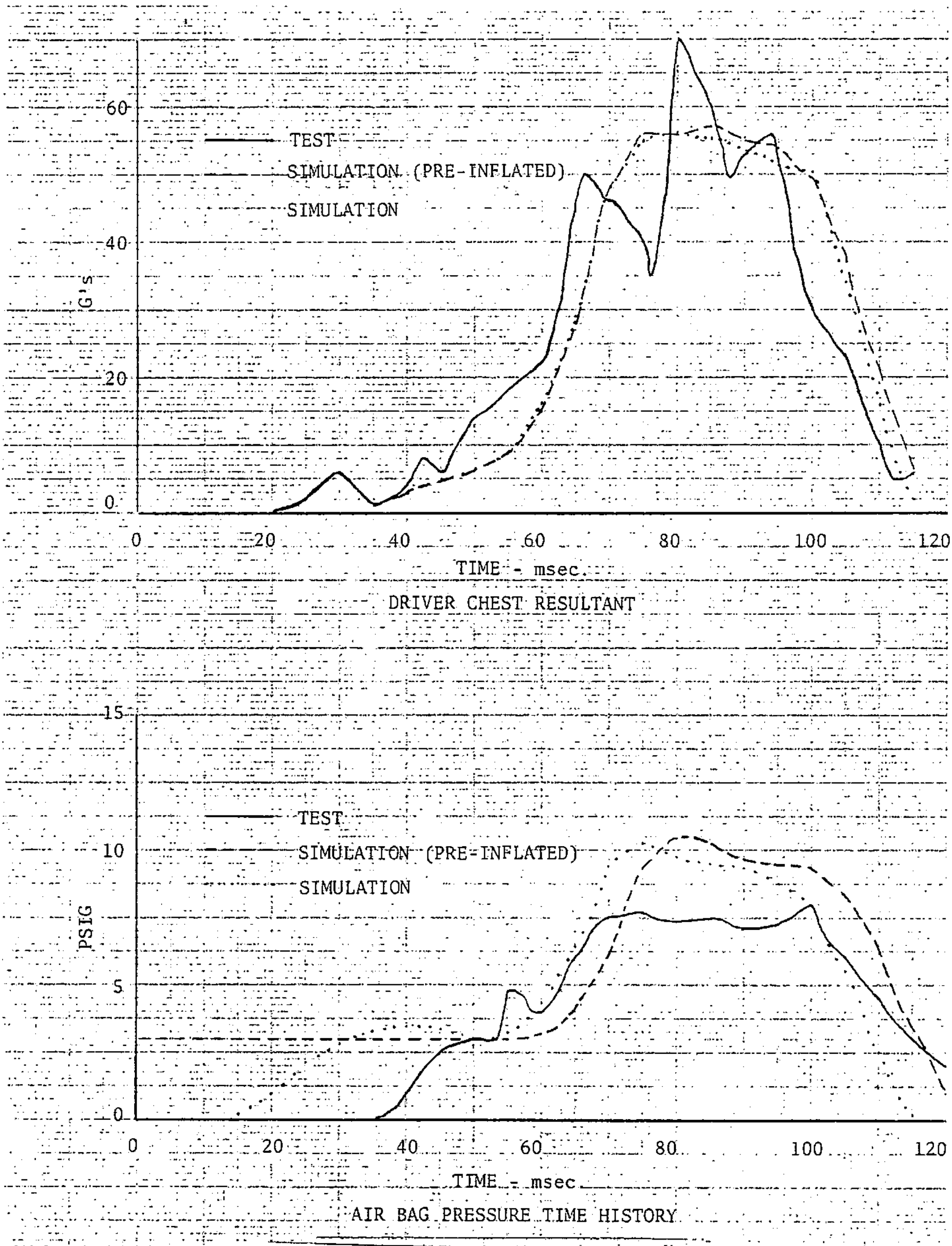
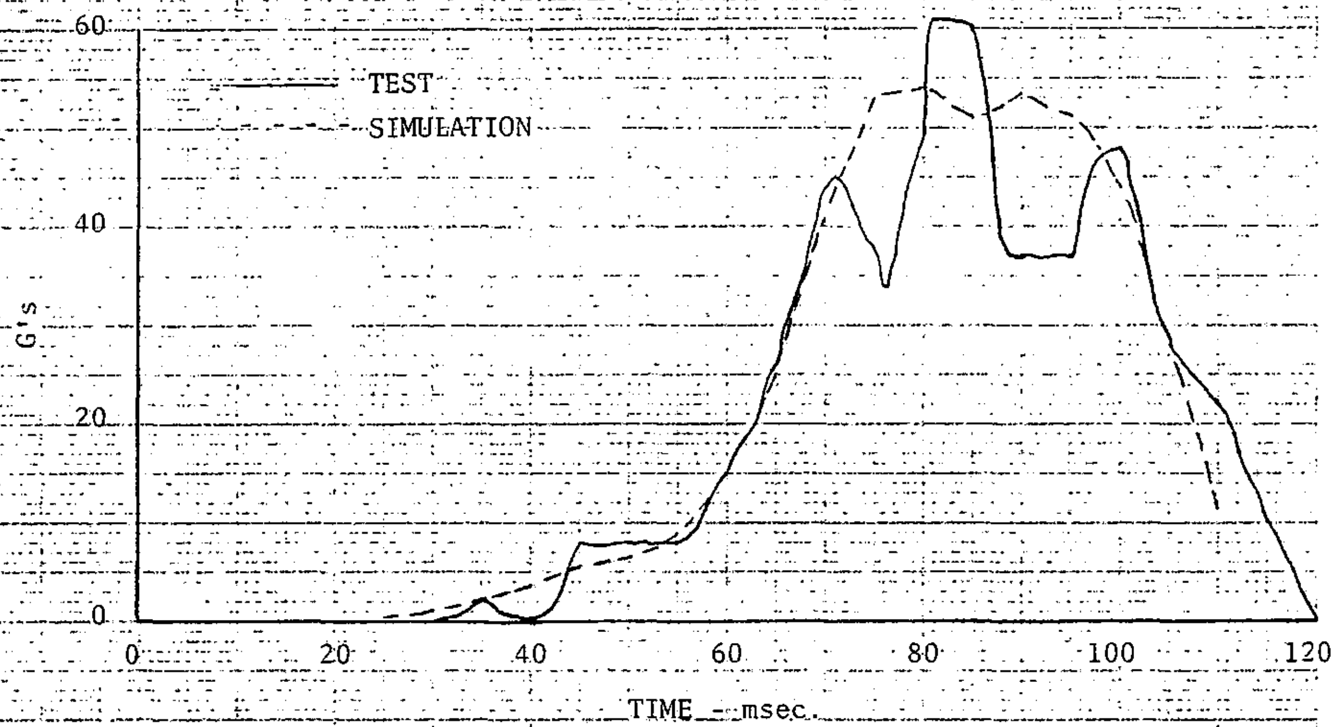
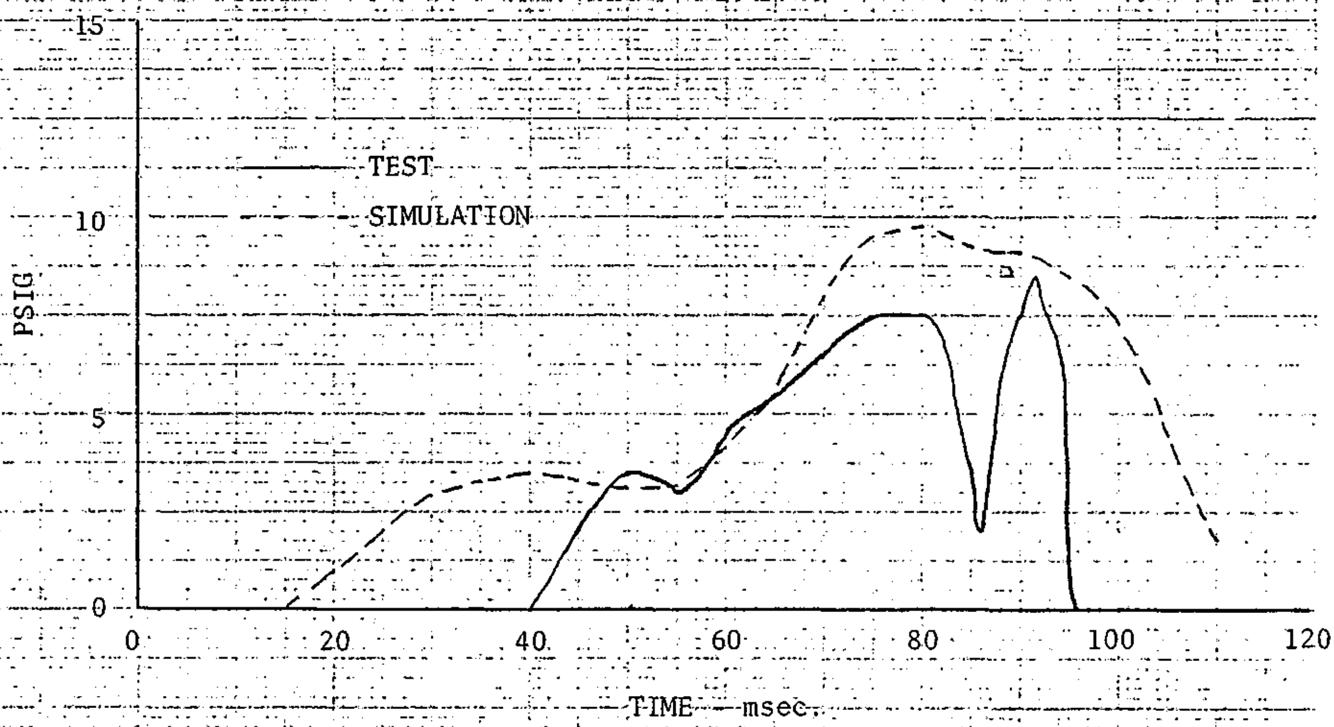


Figure 3-8 46 MPH VOLVO SLED TEST COMPARISONS



DRIVER CHEST RESULTANT



AIR BAG PRESSURE TIME HISTORY

Figure 3-9 42 MPH VOLVO SLED TEST COMPARISONS

Also included in Figure 3-8 is a simulation of the Volvo system using a preinflated 3 psig bag. No appreciable differences for either the torso or air bag pressure time histories are apparent when these data are compared to those using the Thiokol Inflator. This tends to place credence in the assumption that using a preinflated bag does not significantly affect the simulation results and eliminates the need for inflator performance input data.

Conclusions

Based upon the results presented, the following concluding statements may be made regarding the predicted performance characteristics of the driver air bag system:

- Forty mph protection can be provided in the RSV for the 5th percentile female and 95th percentile male with appropriately tuned components. Forty-five mph performance can be provided for the 50th percentile male occupant with the same system.

- The peak torso deceleration is linearly proportional to the steering column collapse force and inversely proportional to the effective torso mass. The column stroke length is inversely proportional to the column collapse force.

- For constant column stroke length, increasing bag pressure from 3 to 5 psig reduces the peak torso deceleration by 5 to 10 g's. For the same column collapse load, increasing the bag pressure reduces the required column stroke 1 to 2 inches.

- For constant column stroke length, reducing the torso-bag deployment point distance by 4 inches reduces the peak torso decelerations by 10 to 15 g's. For constant column collapse load, decreasing the torso-deployment point distance, reduces the required column stroke by 3 to 4 inches.

- The air bag's major function is to improve occupant ridedown and not to dissipate energy.

- Performing the modeling with a preinflated bag does not appreciably affect the results of the simulation.

The simulations provided a strong indication that improved restraint could be achieved in the RSV with a driver air bag. Since it was planned to use an "off the shelf" inflator for the RSV driver air bag, bench tests were next performed to determine the range of bag size/volumes that could be utilized.

3.2 Static Bag Tests, RSV Driver Air Bag System

Static bag firings were performed to compare the unvented pressure time history for three alternative driver air bags, and to assess the potential contact area provided by these bags. These tests were conducted using a Volvo steering wheel and uploaded Thiokol driver inflators. The inflators contained 110 grams of propellant and had a screen pack height of .7 inches.

The bags were constructed of two circular pieces of neoprene-coated, ripstop nylon fabric sewn together. Flat bag diameters of 27, 28.5 and 30 inches were utilized. These bag diameters correspond to an inflated bag volume range of approximately 2.1 and 2.7 cubic feet.

The pressure time histories for these tests are presented in the accompanying Figure 3-10. Also included are photos (Figures 3-11 to 3-13) of the inflation process for each bag. Peak bag pressures of 5, 3.6 and 1.5 psig were attained, respectively for the 27, 28.5 and 30 inch flat diameter bags. Movie data indicate that, when deployed, each bag extended rearward approximately 14 inches. A deployment time range of from 22 to 30 milliseconds was observed in going from the smallest to the largest size bag. Deployment time is defined as that time required after squib fire for the air bag to reach a wrinkle free state.

It was concluded as a result of these tests that the deployment time and bag fill of each bag was acceptable for sled test consideration.

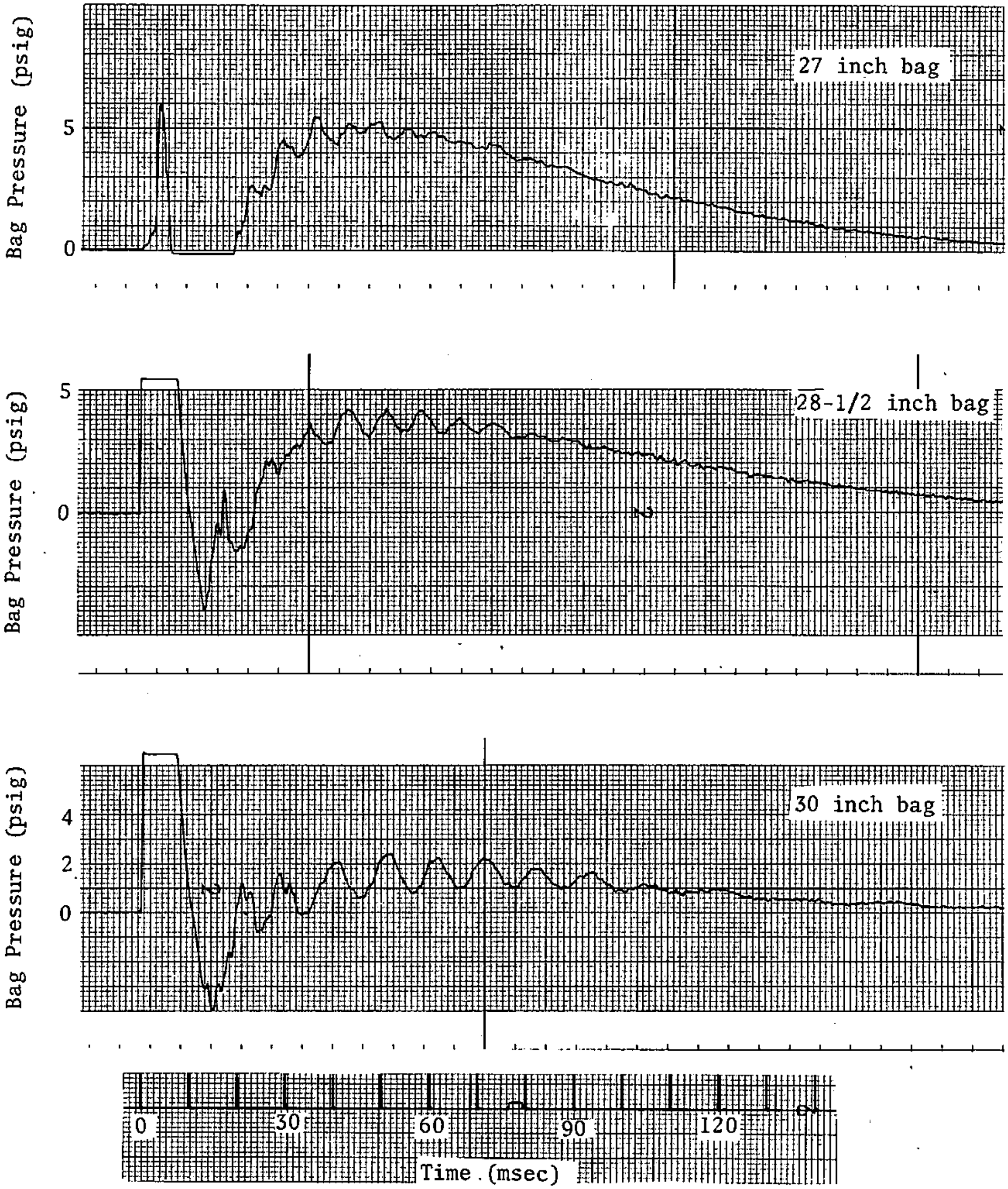
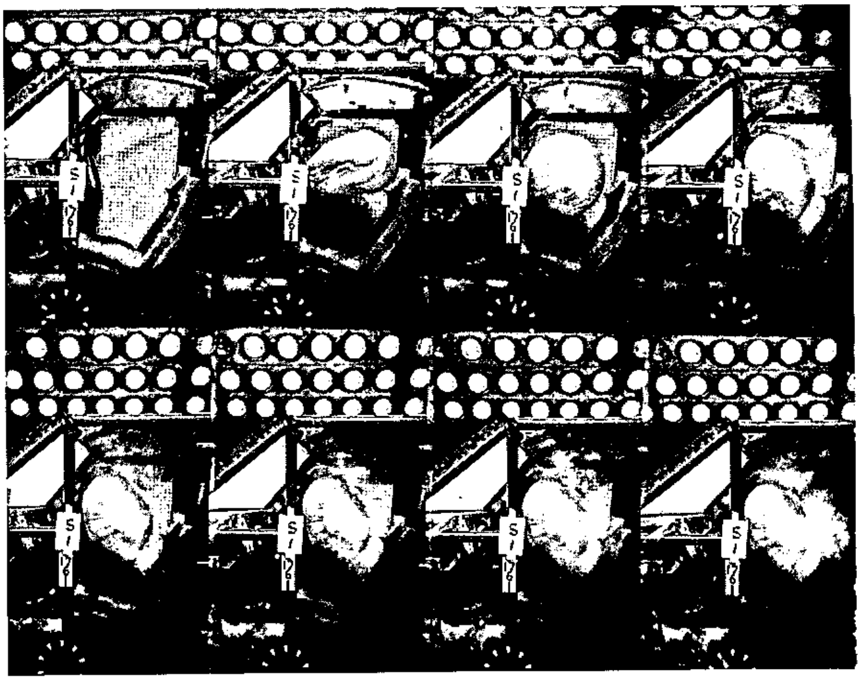


Figure 3-10 BAG PRESSURE TIME HISTORIES

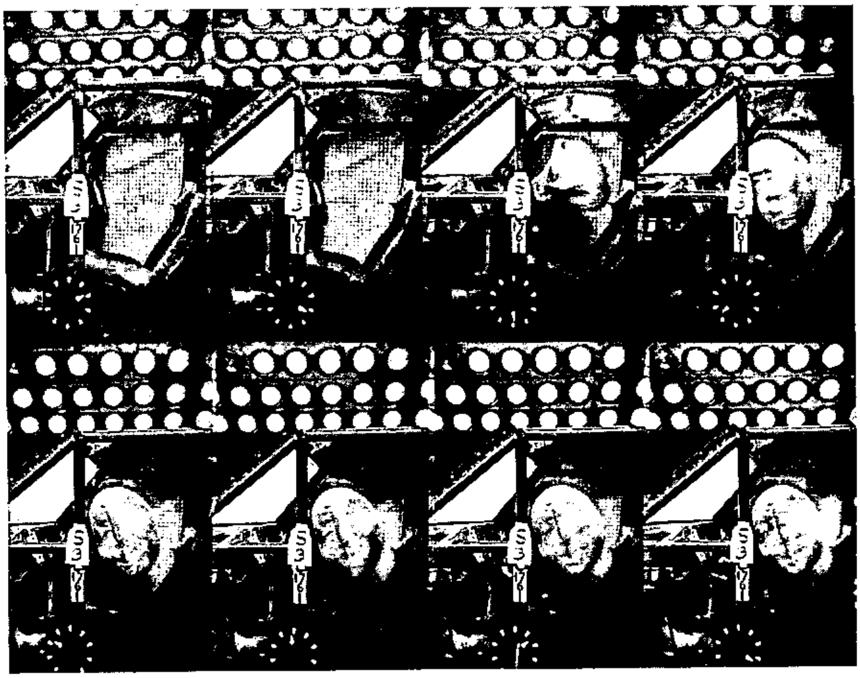
(8) (24) (39)



(59) (89) (108)

Figure 3-11 27 INCH DIAMETER BAG [time in msec, ()]

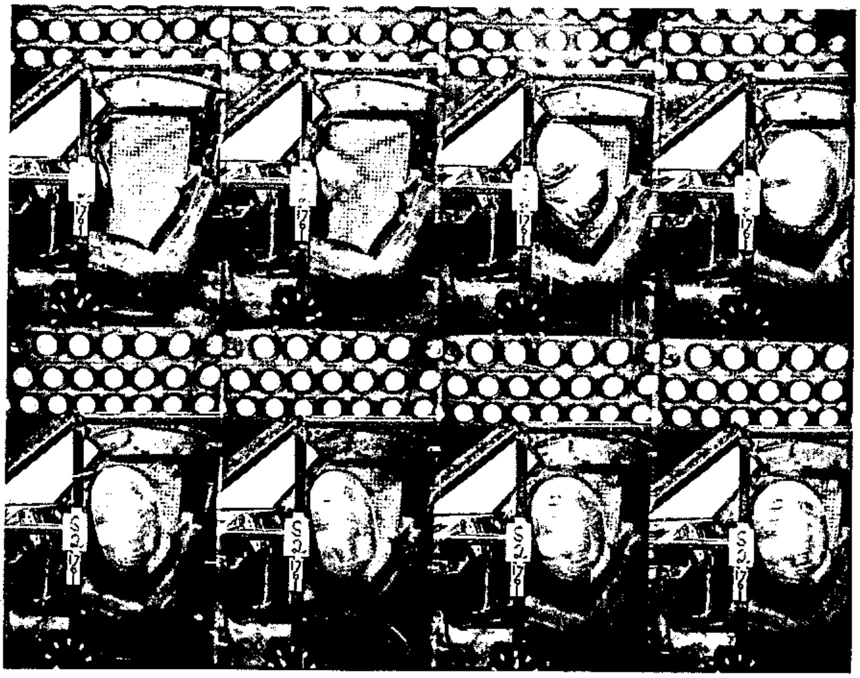
(9) (24)



(42) (57) (75) (94)

Figure 3-12 28-1/2 INCH DIAMETER BAG [time in msec. ()]

(5) (23) (34)



(44) (62) (76) (102)

Figure 3-13 30 INCH DIAMETER BAG [time in msec. ()]

3.3 Static Crush Tests of Column Elements

It is important that no item in the steering assembly fail at low loads with consequent loss of occupant stroke. It is also desirable that all available travel be utilized at loadings just below telerance levels. Static crush tests were performed in support of these criteria. In particular, a base vehicle column (with the column switch stalk in place) was tested to determine break-out forces and switch crush characteristics. This test showed approximately 1/2 inch of travel at virtually no load. Tests were then made of thin-wall cylindrical aluminum columns that could be used as spacers to avoid this free travel. Finally, the steering shaft was designed to collapse axially.

Figure 3-14 shows the crush characteristics of the base vehicle steering shaft and switch cluster. The shaft moved virtually unrestrained (in the absence of the intermediate shaft that connects the steering shaft end to the steering gear box) for 1/2 inch. As the switch bracket crushed between the steering wheel hub and the stationary steering shaft jacket, the load rose rapidly to about 4000 lbf over a crush distance of about 1 inch. This switch crush characteristic was judged to be satisfactory.

Figure 3-15 shows the crush characteristics of short aluminum cylinders that could be used as spacers to remove the free travel distance of the column exhibited in Figure 3-14. Three tube lengths (1 inch, 3/4 inch and 1/2 inch) were tested because the precise spacer length had not been determined at this point; available 1 inch diameter tubing (0.049 inch wall thickness, 5052-0) were used. Force levels shown in Figure 3-15 were in the acceptable range.

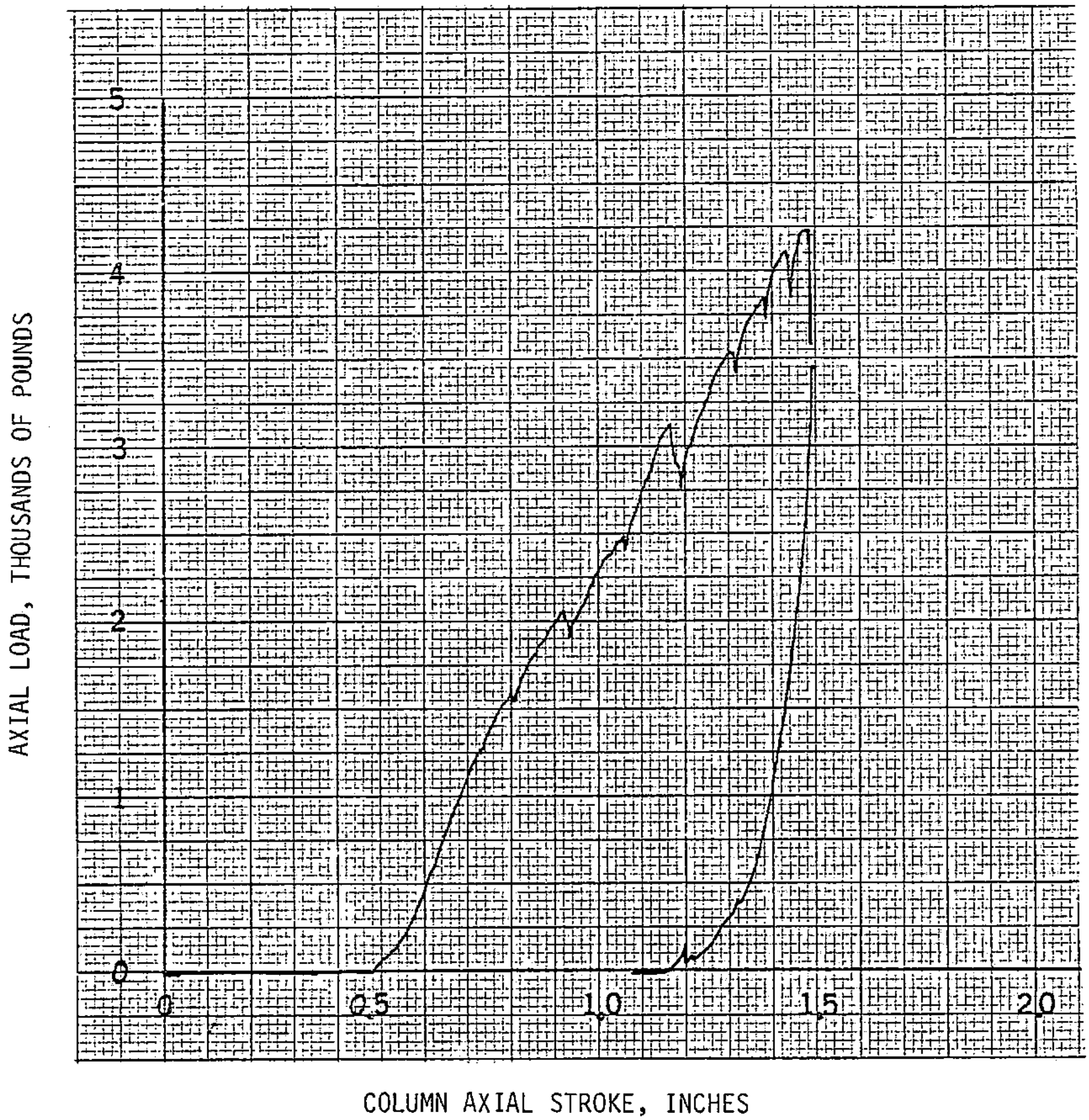


Figure 3-14 BASE VEHICLE STEERING SHAFT AND SWITCH STALK CRUSH TEST RESULTS

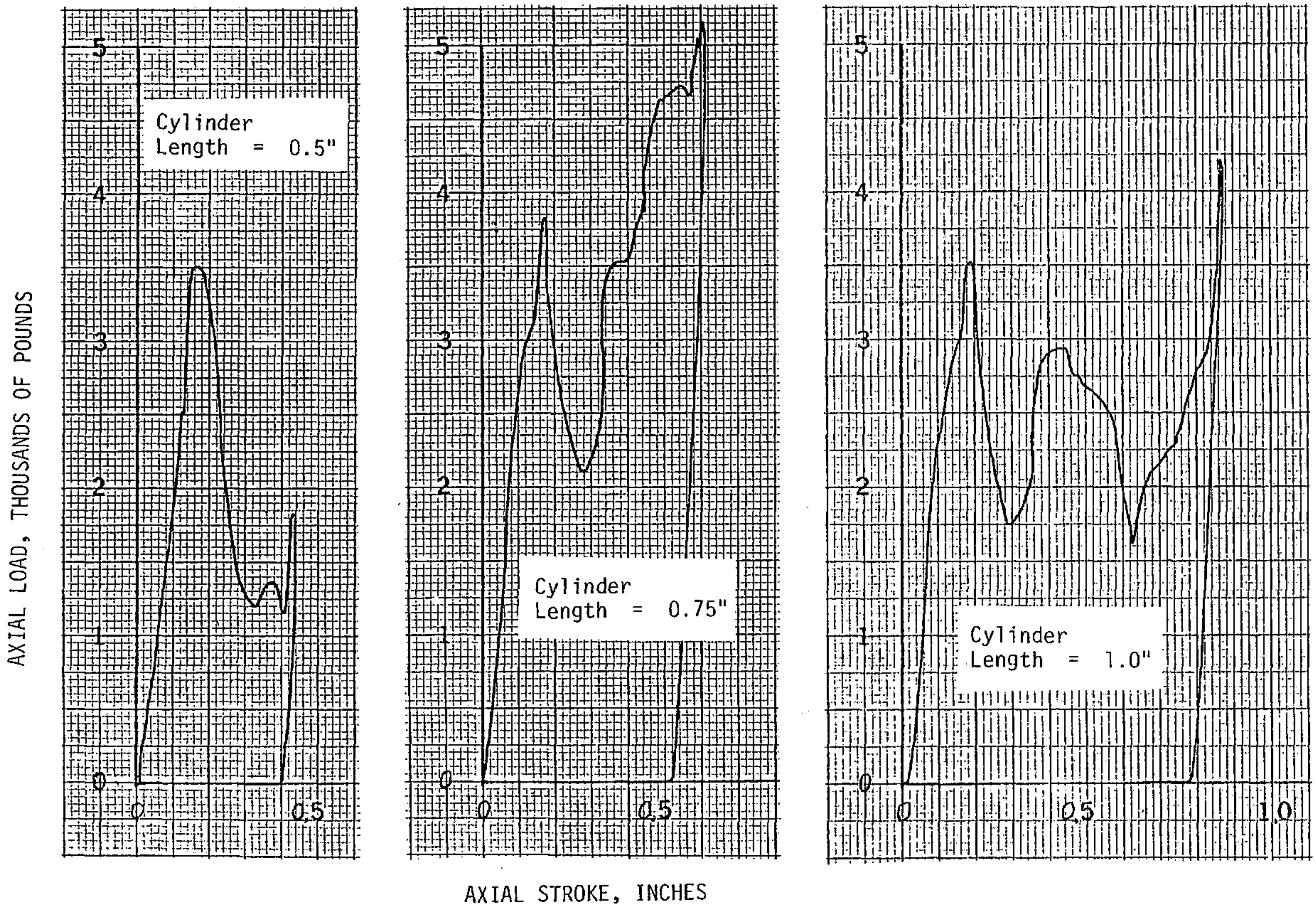


Figure 3-15 STATIC FORCE/DEFLECTION PROPERTIES OF CYLINDRICAL ALUMINUM SPACERS: 1 INCH DIAMETER, 0.049 INCH WALL THICKNESS, 5052-0 ALUMINUM

Figure 3-16 exhibits the static force/deflection characteristics of the energy absorbing section designed as an extension of the steering shaft. It consists of circular end caps joined by a corrugated tube with a cylindrical honeycomb insert. The corrugated tube was made of a short section of the energy absorbing jacket from a Volvo steering assembly; the cylindrical honeycomb insert was made of 1/8 inch aluminum (5052) honeycomb. Figure 3-16 shows that excellent efficiency can be obtained at a force level (3000 lbf) that is appropriate to the air cushion system.

Initial sled testing results revealed that large upward bending moments were imposed upon the steering wheel shaft. As such, the anticipated efficiency of the cylindrical aluminum honeycomb insert was significantly compromised and therefore this energy absorbing section was eliminated from the design.

3.4 Steering Wheel/Dummy Thorax Force/Deflection Measurement

Static measurements were made of the force/deflection characteristics of a Volvo steering wheel forced against a (Part 572) dummy thorax. The hub center of the wheel was aligned with the point of impact used in dummy impact calibrations (Figure 3-17). Figure 3-18 presents the overall results for the wheel and thorax combination and Figure 3-19 presents the load/deflection characteristics attributable to the thorax (internal thorax deflection measurement). Figure 3-19 indicates that the dummy thorax would contribute about 1-1/2 inches of useful stroke to the total restraint system.

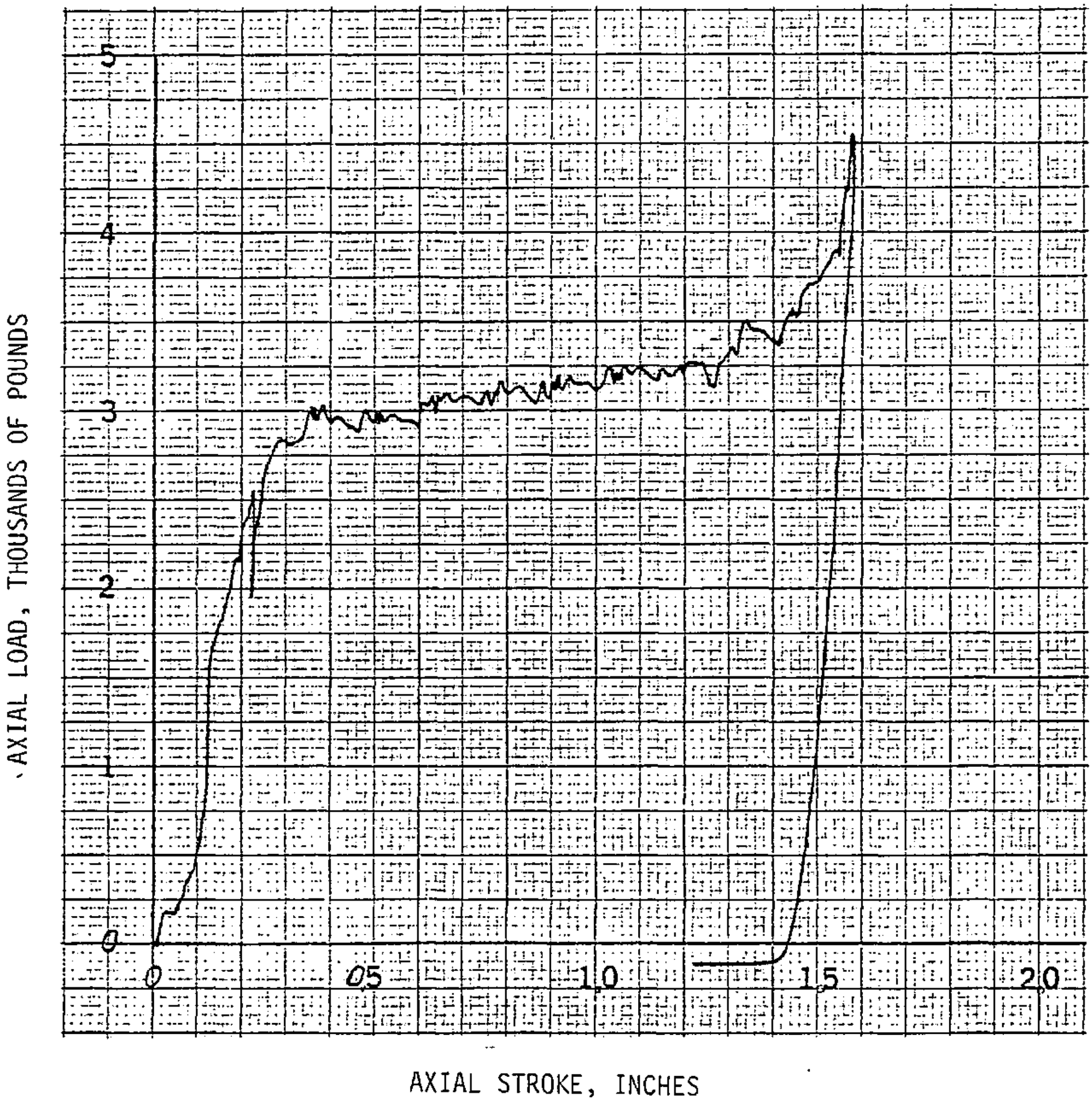
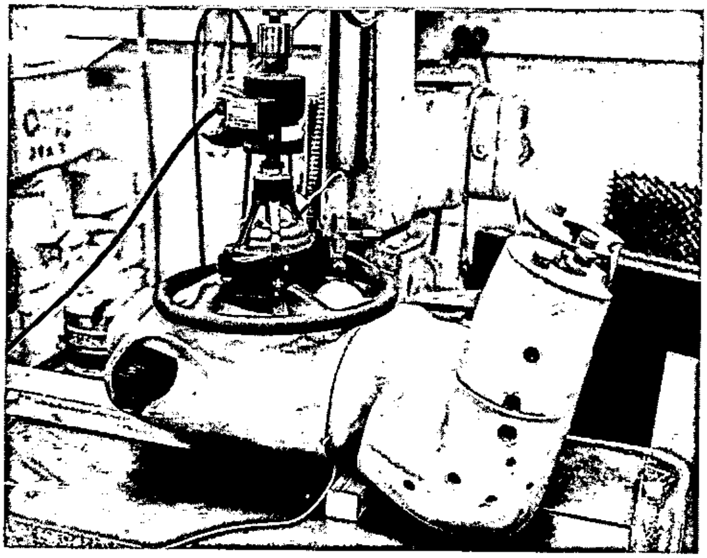
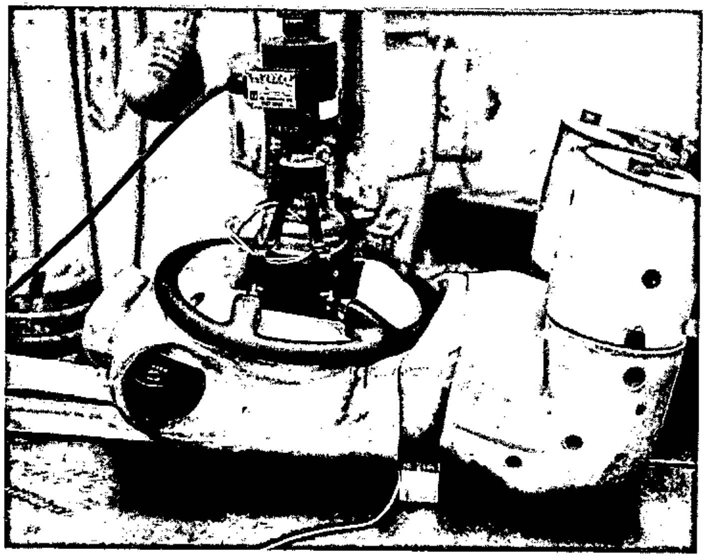


Figure 3-16 STATIC FORCE/DEFLECTION CHARACTERISTICS OF STEERING SHAFT EXTENSION (STEEL CORRUGATED TUBE, CYLINDRICAL ALUMINUM HONEYCOMB INSERT)



Zero Load



2000 lbf Load

Figure 3-17 PHOTOGRAPHS OF WHEEL/THORAX STATIC LOADING TESTS

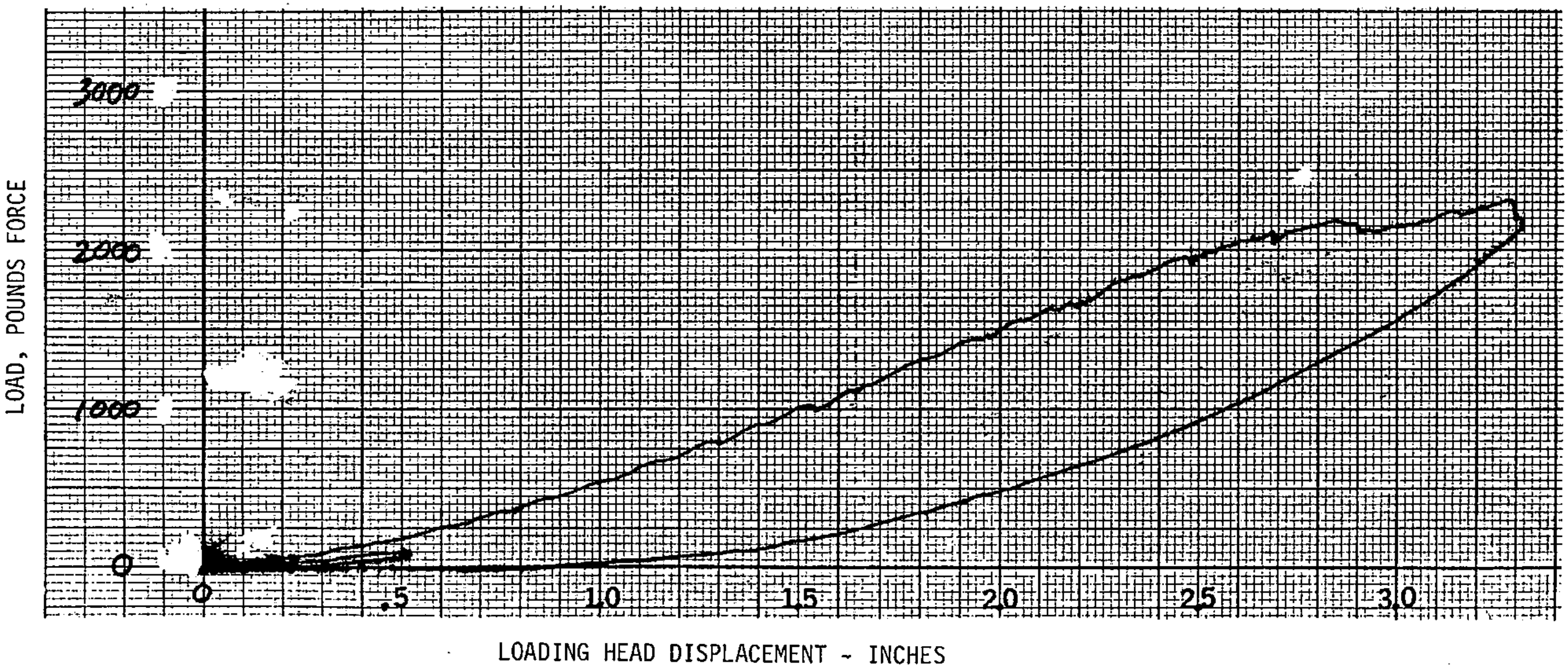


Figure 3-18 STATIC LOAD/DEFLECTION CURVE FOR DUMMY THORAX/VOLVO STEERING WHEEL

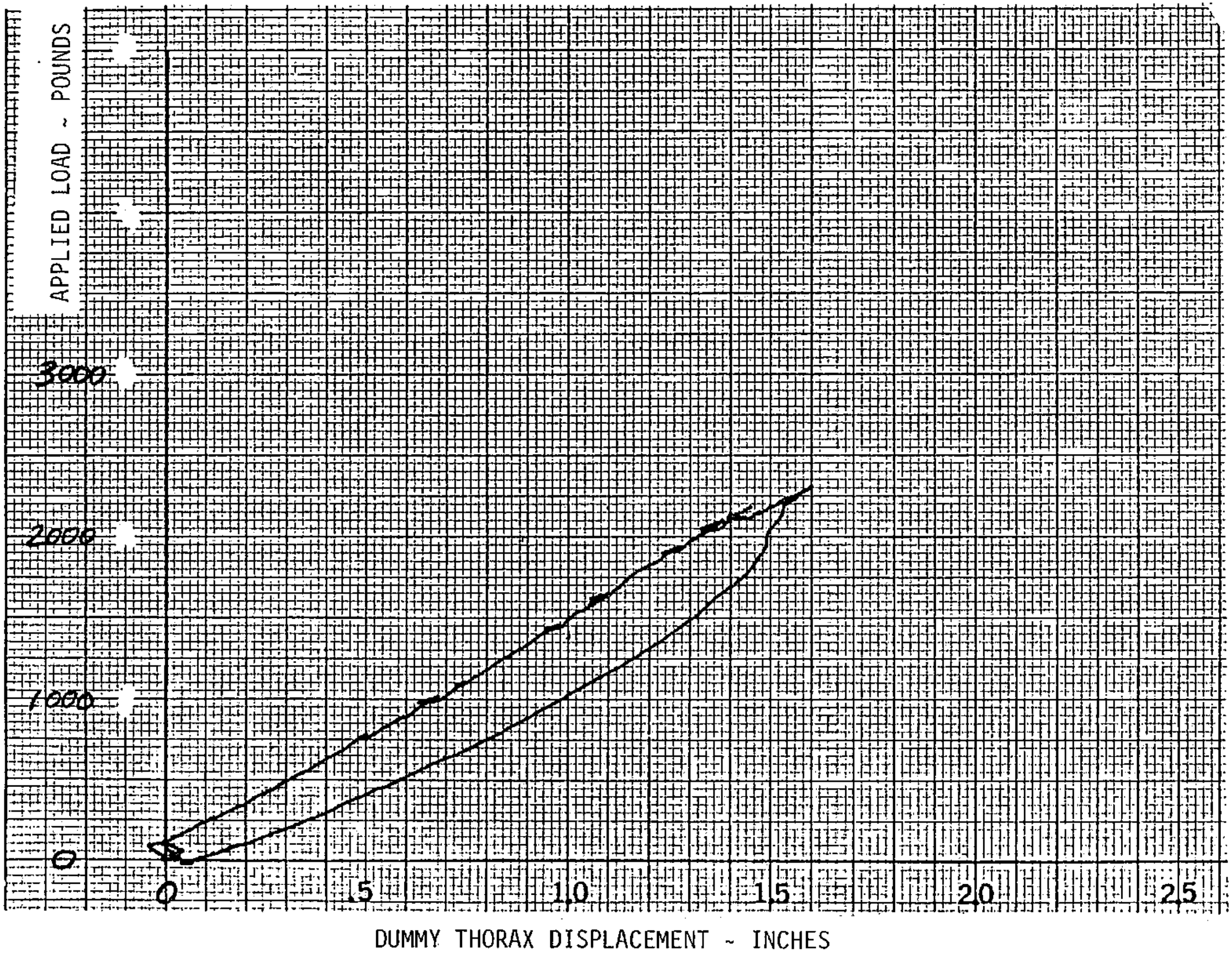


Figure 3-19 PART 572 THORAX FORCE/DEFLECTION CHARACTERISTICS

4.0 DEVELOPMENTAL SLED TESTS

Two series of developmental sled runs consisting of a total of 24 tests were performed to optimize the RSV driver air bag system design. System parameters that were varied in this process included bag size, bag venting, wheel spoke stiffness and occupant size. In all cases, a Thiokol inflator uploaded to 110 grams of propellant and having a screen pack height of .7 inches was used. For these tests, a sensor closure time of 13 milliseconds after initiation of the sled deceleration pulse was electrically simulated. Figure 4-1 depicts a representative pre-test setup.

At the time that this program was being performed, the RSV Phase III vehicle structure was still in the design stage. As such, no experimental structural crash response data was available. The BASHIM lumped mass/spring computer model was utilized to predict the compartment deceleration response for the vehicle. Inputs for the model were based upon the previous Phase II static crush and full scale test data, modified accordingly to reflect the Phase III design changes. The sled pin design for the driver air bag tests was based upon these data. Figures 4-2 and 4-3 compare the deceleration-time and deceleration crush histories of a typical sled pulse with the predicted RSV structural responses. The sled data was shifted 5 msec. in time because it did not simulate the initial low force level bumper response. This point is emphasiz because structural tests performed after the completion of the RSV driver air bag development program indicated the vehicle was significantly stiffer than had been anticipated. Instead of a 40 g maximum deceleration for the occupant compartment, values as high as 70 g's were obtained.

Results of the developmental sled tests are summarized in Tables 4-1 and 4-2. Those data are reviewed in appropriate grouping topics below.

Figure 4-1 DRIVER AIR BAG DEVELOPMENT TEST PRE-TEST PHOTO

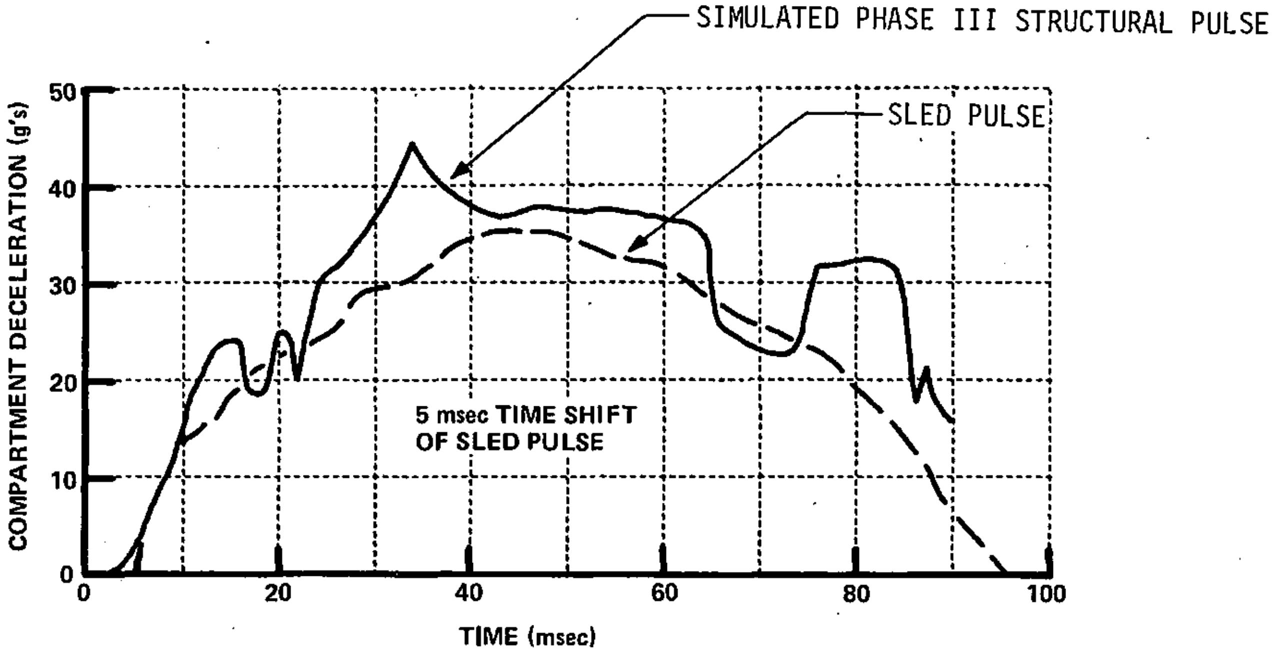


Figure 4-2 **DECELERATION-TIME COMPARISON OF SLED & SIMULATED PHASE III STRUCTURAL PULSES**

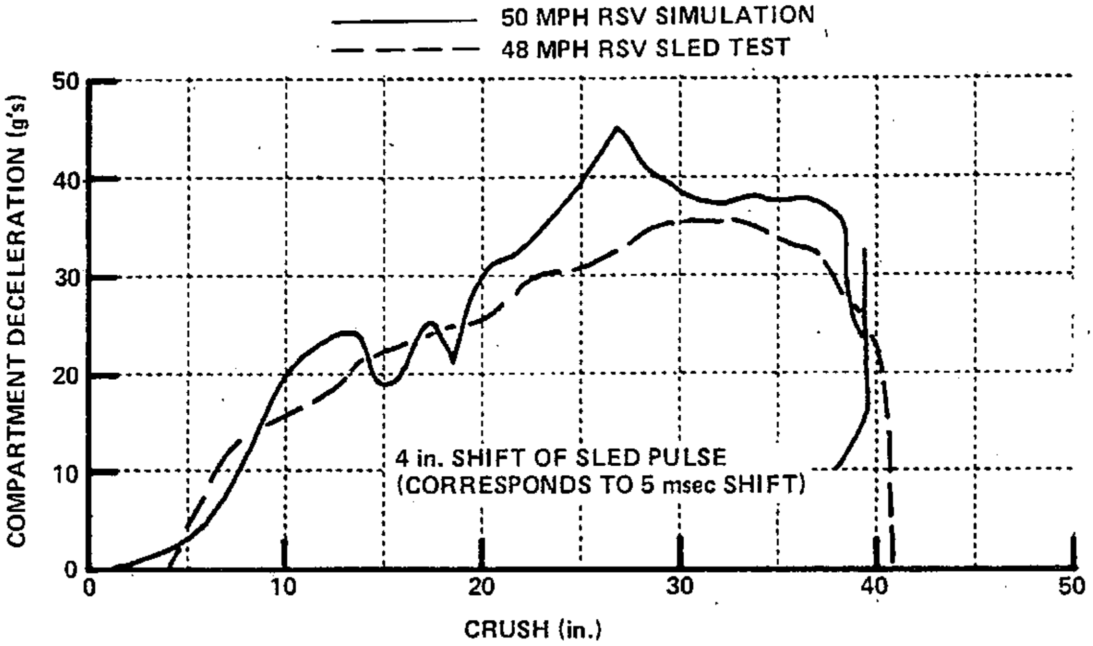


Figure 4-3 DECELERATION-DISPLACEMENT COMPARISON OF SLED & SIMULATED PHASE III STRUCTURAL PULSES

Table 4-1

CALSPAN TEST RESULTS DRIVER AIR BAG - SERIES 1

TEST CONDITIONS						RESTRAINT CONDITIONS 13 Msec. Squib		DUMMY		DUMMY DATA: HEAD			DUMMY DATA: CHEST		DUMMY DATA: PELVIS	DUMMY DATA: FEMUR LOAD lbs.		RESTRAINT DATA All 110gm Infltr	
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.	Bag Size / Vent		SIZE	POSITION	H_R	HSI*	HIC	C_R	CSI*	P_x	L	R	Knee Bar	Bag Pressure
5/17	1766	41.7	31.3	35.7		28.5 / None		#189 50th	Midseat Driver	57	660/ 840	658	60	740/ 820	79	2300	2475	4" HC	10.0
5/18	1767	41.8	32.1	35.8		30.0 / None		#189 50th	Midseat[1] Driver	44	500/ 540	432	68	725/ 755	65	2000	1825	Steel pan removed	(2) 8.25
5/19	1768	41.8	30.2	35.4		27.0 / None		#189 50th	Same	60	780/ 900	652	60	720/ 800	94	2600	2375	1/4 steel plate out	(2) 10.0
5/20	1769	41.8	31.2	35.6		27.0 / None		#189 50th	Same	61	740/ 880	630	55	640/ 810	70	1825	1950	lower steel angle out	11.0
5/20	1770	47.7	35.9	39.8		27.0 / None		#189 50th	Same	67	885/ 940	761	78	1080	82	2200	2200	Same	10.0
5/23	1771	42.0	31.3	35.5		27.0 / None		#189 50th	Same	74/ 100+	1080/ 1760	772	72	920/ 1020	62	1950	1200	RSV Inst Panel	12.75

COMMENTS
(1) Seat moved 1" aft to defined midseat position.
(2) Pressure tap broke at thread.

* SI before and after rebound

Table 4-2

CALSPAN - TEST RESULTS
DRIVER AIRBAG - SERIES 2

TEST CONDITIONS						RESTRAINT CONDITIONS 13 msec Squib		DUMMY		DUMMY DATA: HEAD			DUMMY DATA: CHEST		DUMMY DATA: PEL-VIS	DUMMY DATA: FEMUR LOAD lbs.		RESTRAINT DATA ALL 110 gm INFLATOR: KNEE BAR PENETRATION		RESTRAINT DATA: BAG PRESSURE	
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.	BAG SIZE VENT		SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	L	R		
7/26	1823	41.5	30.4	–		27.0 / NONE	RSV DASH	50th	MIDSEAT	70	1000	804	58	760	60	1680	1230	2 1/4	2 1/8	12.0	(1)
7/26	1824	41.5	30.8	35.1		28.5 / NONE	RSV DASH	50th	MIDSEAT	70	950	792	54	740	60	1720	1220	2 1/4	2	12.5	
7/28	1825	41.2	31.2	38.0		27.0 / NONE	RSV DASH	50th	MIDSEAT	85	1040	829	60	560	64	1480	1080	2 3/8	2 3/8	14.5	(2)
7/29	1826	45.0	34.9	37.1		28.5 / NONE	RSV DASH	50th	MIDSEAT	66	1040	947	59	760	60	1600	1240	2 3/8	2 1/2	10.5	
8/1	1827	44.9	34.6	37.0		28.5 / NONE	RIGID DASH	50th	MIDSEAT	70	800	650	60	600	92	2160	2240	2 3/8	2 7/8	10.5	(3)
8/1	1828	45.1	35.4	36.5		28.5 / NONE	RIGID DASH	50th	MIDSEAT	63	1000		54	700	88	2400	2100	2 5/8	2 7/8	10.3	(4)
8/1	1829	46.0	35.1	36.5	WHEEL SPOKES STIFF-ENED	28.5 / NONE	RIGID DASH	50th	MIDSEAT	–	–	–	56	600	80	2360	1840	2 7/8	2 7/8	10.8	(5)
8/2	1830	45.0	35.1	36.9	REGULAR WHEEL	28.5 / 1.25" DIA.	RIGID DASH	50th	MIDSEAT	70	1200	931	56	660	84	2320	2080	2 3/4	3	11.0	
8/3	1831	15.3	12.2	11.7	REGULAR WHEEL	STOWED BAG	RIGID DASH	50th	MIDSEAT	34	170	116	19	31	42	1040	1060	1 1/8	15/16	THRESHOLD TEST NO DEPLOYMENT	
8/4	1832	47.5	38.1	37.5		28.5 / 1.25" DIA.	RIGID DASH	50th	MIDSEAT	116	1380	1071	65	840	92	2160	2080	2 3/4	2 7/8	9.5	
8/4	1833	47.6	37.6	37.5		28.5 / 2.0" DIA.	RIGID DASH	50th	MIDSEAT	–	–	–	–	–	–	–	–	2 5/8	2 1/4	–	(6)
8/5	1834	45.2	36.0	36.7		28.5 / 2.0" DIA.	RIGID DASH	50th	MIDSEAT	58	800	710	52	620	88	2080	2100	2 9/16	2 1/2	9.2	

(1) STEERING SHAFT BROKE
(2) SEAM OPENED ON RIGHT SIDE OF BAG
(3) BAG TEAR ON LEFT SIDE
(4) HEAD DATA EXCLUDES H_Y
(5) BROKEN NECK
(6) ALL DATA LOST

Table 4-2 (Cont.)

CALSPAN - TEST RESULTS
DRIVER AIRBAG - SERIES 2

TEST CONDITIONS						RESTRAINT CONDITIONS 13 msec Squib		DUMMY		DUMMY DATA: HEAD			DUMMY DATA: CHEST		DUMMY DATA: PELVIS	DUMMY DATA: FEMUR LOAD, lbs		RESTRAINT DATA ALL 100 μm INFLATOR: KNEE BAR PENETRATION		RESTRAINT DATA: BAG PRESSURE	
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.	BAG SIZE VENT		SIZE	POSITION	H_R	HSI	HIC	C_R	CSI	P_x	L	R	L	R		
8/8	1835	46.0	36.4	36.9		28.5" / 2.0" DIA.	RIGID DASH	5th	FORWARD	64	1200	947	70	1080		1500	2000	1-5/8	1-3/8	8.0	
8/9	1836	45.5	37.3	36.7	-	28.5" / 2.0" DIA.	RIGID DASH	95th	REAR	120	2000+	1835	84	1160	76	2400	2300	2-1/2	3-3/8	9.75	(1)
8/12	1840	42.0	31.9	35.3		28.5" / 2.0" DIA.	RIGID DASH	95th	REAR	92	1400	1235	63	860	84	2160	2560	2-3/4	3-7/8	11.6	
8/15	1841	42.2	31.4	35.2		28.5" / 2.0" DIA.	RIGID DASH	5th	FORWARD	60	920	671	58	900		1560	1560	1-3/4	1-3/4	7.0	
8/15	1842	40.6	31.1	35.0		28.5" / 2.0" DIA.	RIGID DASH	95th	REAR	122	1680	1348	68	760	80	2200	2400	3	3-7/8	9.0	(2)
8/16	1843	47.5	37.3	37.6		28.5" / 2.0" DIA.	RIGID DASH	50th	MIDSEAT	68	960	773	58	690		2100	2240	2-1/2	2-1/2	8.75	

(1) CHEST STROKE EXHAUSTED
(2) HEADER CONTACT

Choice of Bag Size

Sled Runs 1766 to 1769 (see Table 4-1), examined the range of driver performance that could be expected as a result of varying bag size from 27 to 30 inches (flat diameter). Venting was not provided. Furthermore, steering column components such as the column support bracket, shaft jacket, steering column shaft and switch cluster were not allowed to deform. Other than bag size changes, the only run-to-run test differences were with respect to the aluminum honeycomb knee restraint support structure. Those changes were conducted in order to obtain the backup structure for the knee restraint that was most representative of the RSV collapsible instrument panel.

The data indicated that there was improvement in head response with softer bags (going from 27 inches to 30 inches in flat diameter) with a corresponding degradation in chest response. Chest response appeared to be the limiting factor. For this reason, the 30 inch diameter bag was eliminated from further consideration. Both the 27 and 28.5 inch diameter bags produced acceptable results with respect to accelerations and kinematics. Sled runs were subsequently performed to finalize a choice for bag size. Runs 1823 and 1825 were unvented 27 inch bag tests while Run 1824 used an unvented 28-1/2 inch diameter bag. Each test was performed at approximately 41.5 mph (see Table 4-2). The restrictions for preventing deformation of the RSV steering column assembly components (bracket, pedal support bracket, shaft, etc.) were removed, and Phase III instrument panels with integrated knee restraints were used.

The first 27 inch bag test (1823) was repeated (Run 1825) because in the first test the steering shaft failed at the mating point where an extension shaft section (Volvo wheel spline adapter) was attached to a base vehicle C6 shaft. The base vehicle C6 shaft is notched at that location. This problem was corrected by the subsequent fabrication of one-piece shafts.

A bag tear was experienced in the second 27 inch diameter bag test. The injury criteria were still satisfied for both tests, however. Each of these failures occurred late in the occupant time response histories so that comparison with the 28-1/2 inch bag test (Run 1824) was possible. The 28-1/2 inch bag demonstrated improved head, chest and rebound response characteristics and, therefore, was chosen for continued testing. Head and chest resultant accelerations of 70 and 54 g's (respectively) were obtained for the 28-1/2 inch bag in Run 1824. As a result of these successful demonstrations at 41.5 mph, subsequent testing was performed at 45 and 47.5 mph.

45 MPH Unvented Bag Tests

Once the driver bag size was chosen, four 45 mph sled tests were performed using unvented 28-1/2 inch flat diameter bags. (Refer to sled tests 1826, 1827, 1828, and 1829 in Table 4-2.) The objectives of these tests were to determine if the 45 mph impact performance characteristics of the Phase III instrument panel/knee restraint could be simulated in an efficient manner and to assess the effects of stiffening the Volvo wheel spokes.

The Phase III RSV instrument panels were prototype parts that required significant time and expense to fabricate. It was therefore desirable, from a program economy and efficiency standpoint, to simulate the lower torso restraint provided by the instrument panel with its integral aluminum honeycomb insert in the remainder of the development testing. Final evaluation sled testing would, of course, use final system design components.

A nondeformable frame structure was fabricated to support an aluminum honeycomb block contained in a sheet metal pan ("Boilerplate knee restraint").

The contour and position of the aluminum honeycomb in the "boiler-plate" design was the same as that in the instrument panel. The honeycomb could crush 2 to 3 inches. The support sheet metal pan could also deform 1 to 2 inches to simulate instrument panel substrate translation and deformation.

The first 45 MPH sled test, Run 1826, was performed with the RSV Phase III instrument panel. The instrument panel used is depicted in Figure 4-4. The chest resultant acceleration was just below the limit at 59 g's; head response was also acceptable (66 g's peak resultant acceleration). Rebound accelerations were high, but this was not viewed as a problem since this was an unvented bag test. Furthermore, relatively minor deformation was observed at the column and pedal support bracket locations.

In the following two sled exposures, Runs 1827 and 1828,* the potentially crushable steering column pedestal bracket, pedal support bracket and instrument panel were replaced by a rigid column bracket and the boiler-plate frame structure with the collapsible honeycomb.

The driver head and chest responses from Runs 1827 and 1828 were found to be reasonably similar to the data obtained from Run 1826. In Figure 4-5 the chest resultant responses from the three tests are displayed. Occupant kinematics (chest and hip travel) are also very similar for all three runs. The only major difference between the instrument panel and boilerplate tests was with respect to the femur responses. Although knee penetrations were essentially identical, the RSV Phase III instrument panel was 600 to 800 pounds softer per femur. This resulted in peak pelvis accelerations which were 30% lower with the actual instrument panel (60 vs. 90 g's).

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*Run 1827 was repeated because a slight bag tear occurred.

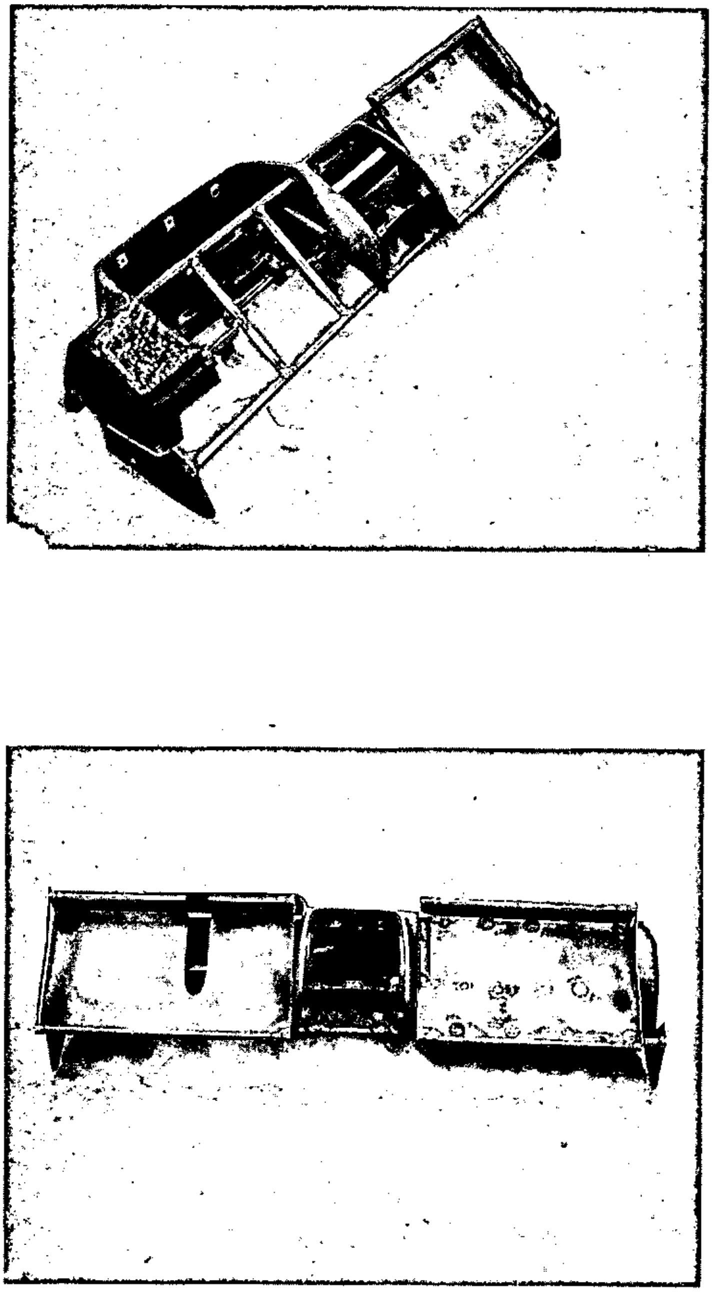


Figure 4-4 PHASE III RSV INSTRUMENT PANEL STRUCTURE (WITHOUT ALUMINUM HONEYCOMB IN PANS)

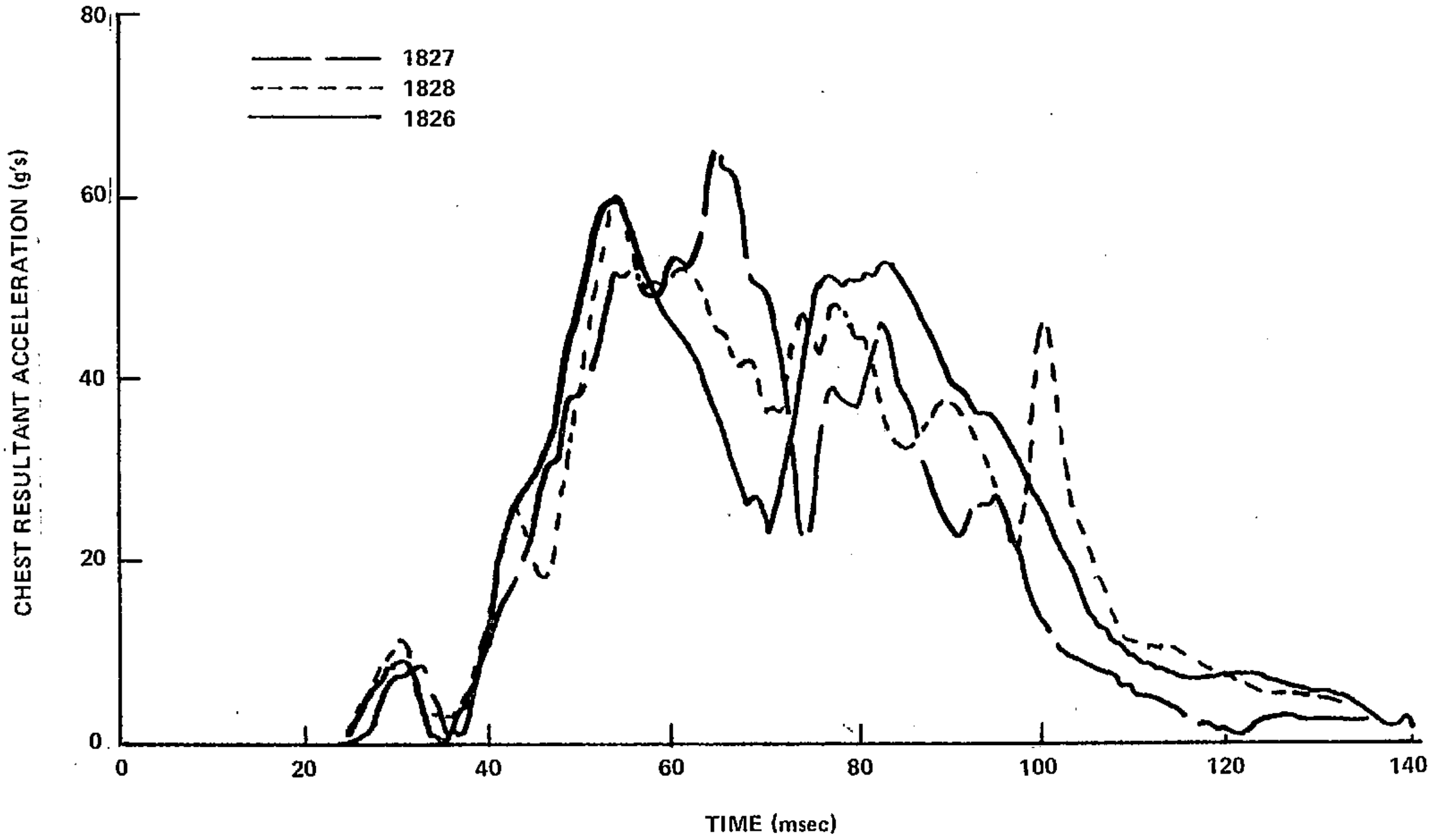


Figure 4-5 COMPARISON OF CHEST RESULTANT ACCELERATIONS FOR TESTS 1826, 1827, AND 1828

Thus, the data indicated that upper body occupant performance was very reasonably approximated by the boilerplate design. Lower body kinematics were also similar. Lower body injury performance measures were improved with the RSV instrument panel.

Based upon these findings, continued use of the boiler plate design to simplify testing was justified with RSV Phase III instrument panels to be used only in final validation sled testing.

Sled test 1829 was performed to assess the effects of modifying the stiffness of the Volvo GT sport wheel collapsible spokes. Z-straps, 3/8 inch wide, made from 1/8 inch thick mild steel were welded to the upper Volvo spokes. In addition, a 3/8 inch wide collar (1/8 inch stock) was welded around the base of the spokes. The intent of these modifications was to improve the initial chest onset response by increasing the forces required to form plastic hinges in the wheel spokes. However, the test results did not indicate any change in chest accelerations when compared to the previous two sled tests (Runs 1827 and 1828).

It should be noted that column stroking along the shaft axis did not occur in any of the above tests. Instead, the shaft was bent upward. The effective stroking distance was increased with respect to that which would have been obtainable if the column collapsed along the axis. Up to three inches of steering wheel hub forward translation were realized with upward shaft bending. This amount of stroke was not available in the axial mode. Occupant kinematics nevertheless remained acceptable.

Based upon the results of these four 50th percentile male driver sled tests, it was concluded that improved head and chest responses could be achieved at 45 mph.

Vented Bag Tests

Four sled tests were performed to determine the appropriate vent characteristics for the driver air bag system. Sled tests with the 50th percentile dummy were performed at 45 and 47.5 mph with two different vented bags. A boiler plate knee restraint was used in each case.

Sled tests 1830 and 1832 were 45 and 47.5 mph sled tests using a 1.5 inch diameter vent hole in the 28.5 inch flat diameter bag. The vent area, excluding gas leakage area through the seams, was 1.77 inches square. In Sled Run 1830 (45 mph) the injury criteria were satisfied. Head performance was improved (70 g's for head resultant) while the chest resultant acceleration remained the same as in previous unvented bag tests (56 g's).

Since the occupant had not exhausted the available torso displacement, Run 1832 was performed at 47.5 mph with the same vent characteristic. Results from the higher speed test, Run 1832, indicated excessive head restraint. The bag pressure was too high and hyperextension of the neck consequently occurred. Chest response was also above the acceptable injury criteria at 65 g's. However, the data and film results showed no evidence of the chest bottoming out.

Since torso displacement was still available and the head restraint had been excessive, the vent area was increased in the subsequent sled run. Test 1834 was performed at 45.2 mph with a bag having a 2 inch diameter vent. Thus, the vent area was approximately twice that available with the 1.5 inch diameter hole. Satisfactory results were obtained with respect to both accelerations and kinematics. The head and chest resultant accelerations were 58 and 52 g's, respectively. The sled velocity was increased to 47.6 mph in the following run with the same 2 inch diameter vent hole bag. Kinematics appeared acceptable; unfortunately, all the accelerometer data was lost on that test.

The results obtained with the 2 inch diameter vent bag were sufficiently satisfactory at that point to justify examination of system performance with other occupant sizes.

Subsequently, the higher speed test was repeated, sled test 1843 (47.5 mph) and satisfactory performance was demonstrated. The resultant accelerations for the head and chest were 68 and 58 g's. Corresponding HIC and CSI numbers were 773 and 690.

Threshold Speed Test

A 15.3 mph non-deployed air bag test (Run 1831) was performed to evaluate the performance of the wheel and knee restraints when impacted by a 50th percentile occupant at speeds below the threshold required to activate the driver inflator. The threshold speed is an 11 mph velocity change for the RSV sensor. The 15 mph test velocity was selected to be conservative. A boiler plate dash with collapsible knee restraints and a stowed air bag were used. Occupant performance was excellent with respect to kinematics, deceleration and rebound. Very little deformation of the wheel was apparent. Peak head and chest resultant accelerations were 34 and 20 g's, respectively. The HSI was 170 and CSI was 31.

5th Percentile Female Sled Tests

Driver air bag performance with the 5th percentile female was evaluated at 46 and 42.2 mph in sled tests 1835 and 1841.

Results of the 46 mph exposure (Run 1835) indicated that the air bag system was simply too stiff for the lightweight female at this high speed. A chest resultant acceleration of 70 g's was obtained. Head results, however, were acceptable.

The test speed was lowered to 42.2 mph for Run 1841. Satisfactory injury criteria results were obtained. The head and chest resultant accelerations were 60 and 58 g's, respectively.

95th Percentile Male Sled Tests

Three driver air bag sled tests were performed with a 95th percentile male-sized dummy. Test speeds were 45.5, 42 and 40.6 mph. These data appear in Table 4-2 as sled Runs 1836, 1840 and 1842.

Results for the 95th driver at 45.5 mph (Run 1836) were, as expected, the opposite of those experienced by the 5th female at 46 mph. For the 95th male, the system was too soft. The chest "bottomed out" on the steering wheel.

In the following 95th driver exposure (Run 1840), the sled speed was reduced to 42 mph. At this test condition, the driver just barely exceeded the stroke capacity of the air bag system. A chest resultant acceleration of 63 g's was recorded. Head results also exceeded the injury criteria; the HIC number was 1235.

Sled Test 1842 was then performed at 40.6 mph. For this run, poor results were obtained due to driver contact with the header. Since this did not occur in the previous two 95th driver tests, it was clear that the limited head room in the RSV was marginal for 95th percentile occupants.

Based upon the findings obtained, it appeared that acceptable dummy kinematic and injury criteria results could be obtained up through the 47 to 48 mph speed range for a 50th percentile male with the RSV driver air bag system. For the 5th percentile female, the upper limit appeared to be 42-43 mph. Acceptable performance at 40 mph was postulated for the 95th percentile male driver provided that the header contact problem was reduced.

The basic driver air bag design was finalized at this point and evaluation sled testing with "production" hardware was begun. Prior to discussing those results, the system chosen for evaluation sled testing is summarized in detail.

5.0 RSV DRIVER AIR BAG SYSTEM DESCRIPTION

At the conclusion of the developmental sled testing, the finalized driver air bag system was defined. Components such as the sensors, diagnostic box, and instrument panel were direct carry over items that have been documented in detail in the main Calspan RSV program. Specific driver air bag components such as

- steering wheel
- steering wheel shaft
- air bag manifold
- inflator
- air bag
- air bag deployable cover
- slip rings
- attachment hardware

were thoroughly documented in a package of design drawings that was forwarded to the NHTSA. Table 5-1 details the contents of that final design drawing package.

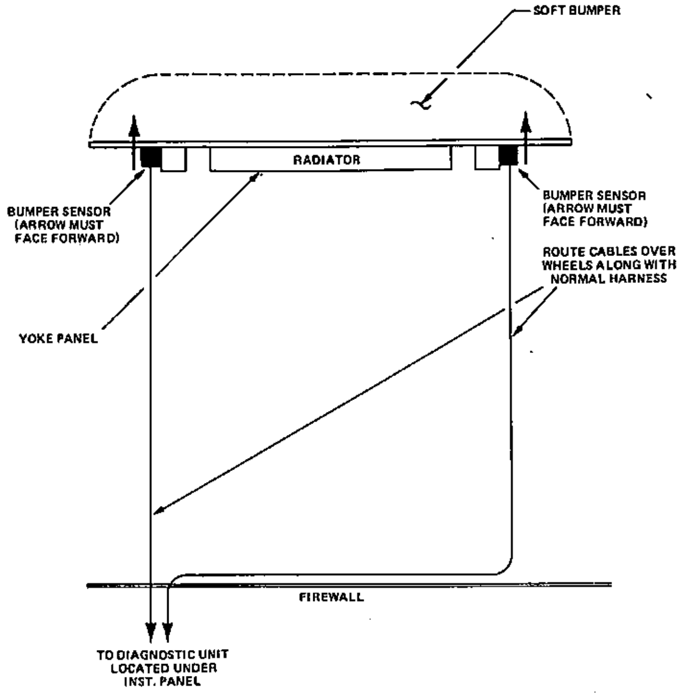
A general summary of the system components is presented below.

- Sensor - Allied Bumper Impulse Detector (2) located on either side of the radiator. Response time ≈ 13 milliseconds in a 45 MPH frontal collision, see Figure 5-1.
- Diagnostic Box - General Motors 1973/1974 air bag fleet component.
- Slip Rings - General Motors 1973/1974 air bag fleet component.
- Knee Restraint - RSV instrument panel with aluminum honeycomb inserts for lower torso energy dissipation, see Figure 5-2.

Table 5-1

RSV DRIVER AIR BAG RESTRAINT SYSTEM DRAWINGS

Drawing No.	Title
TR78-W89-101	Steering Column & Wheel Assy, Driver Air Bag
TR77-W89-102	Manifold Assem. Driver Air Bag
TR78-W89-103	Air Bag Inflator
TR78-W89-104	Steering Column Jacket Modif. Driver Air Bag
TR77-W89-105	Steering Wheel, Driver Air Bag
TR77-W89-106	Shaft - Steering, Driver Air Bag
TR77-W89-107	Manifold, Driver Air Bag
TR78-W89-108	Seal-Brass, Driver Air Bag
TR78-W89-109	Ring-Mtg., Driver Air Bag
TR78-W89-110	Air Bag, Assem., Driver Air Bag
TR78-W89-111	Lwr. Steering Wheel Cover, Driver Air Bag
TR78-W89-112	Shaft-Steering Assy., Driver Air Bag
TR78-W89-113	Upper Cover, Driver Air Bag



TOP VIEW OF SENSOR
INSTALLATION POSITION

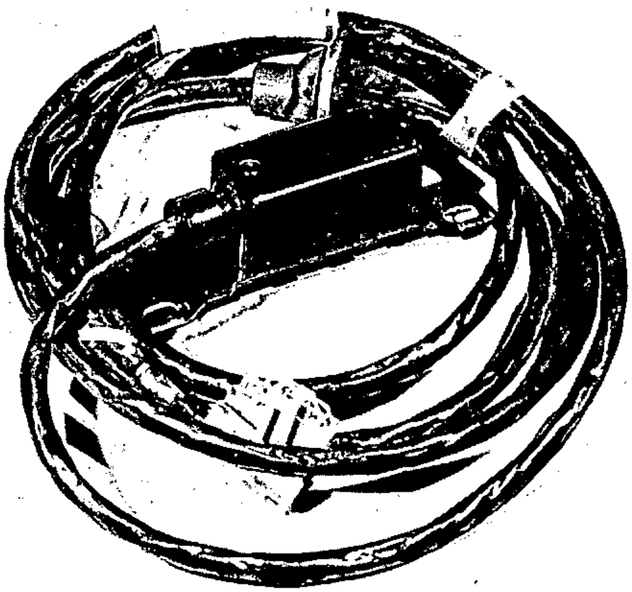
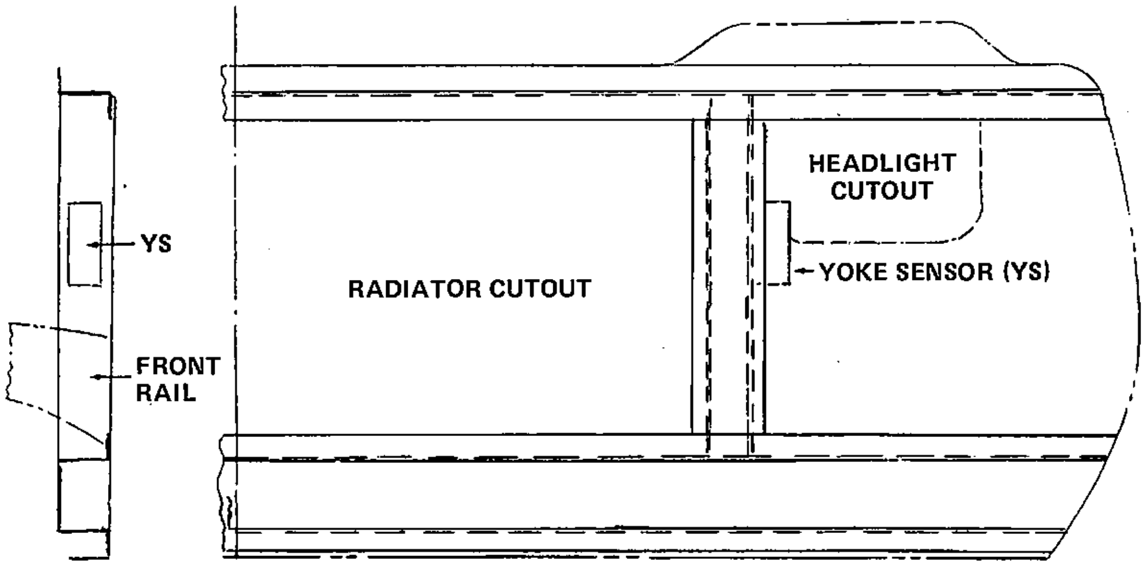


PHOTO OF ALLIED BUMPER
IMPULSE DETECTOR



SENSOR LOCATION WITH RESPECT TO MOUNTING
FACE FOR SOFT FRONT BUMPER SYSTEM

Figure 5-1 BUMPER SENSOR INSTALLATION IN RSV

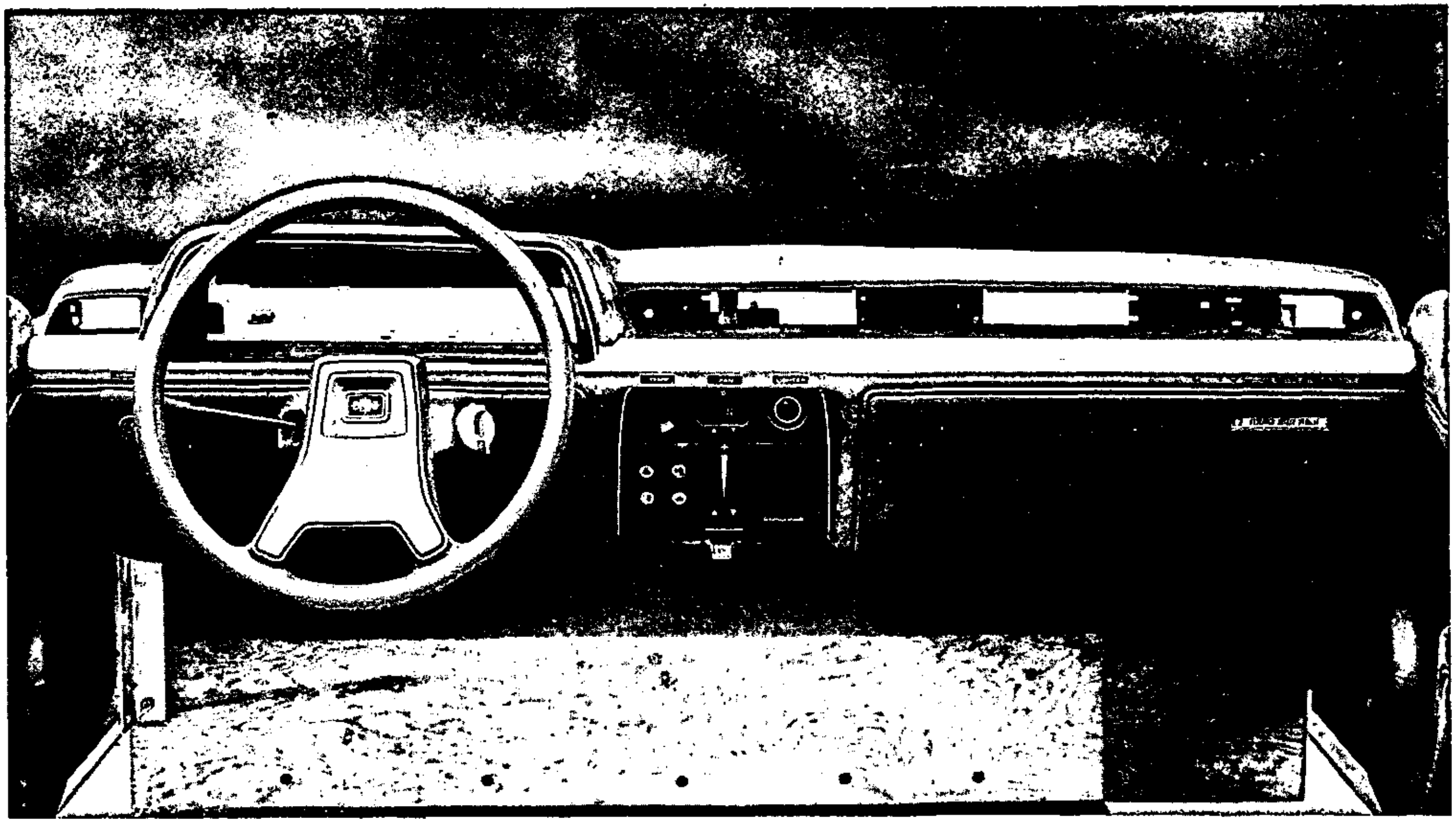


Figure 5-2 STYLING CLAY OF KNEE BLOCKER

- Gas Generator - Thiokol driver inflator uploaded to 110 grams of propellant. Screen pack height = .7 inches; see Figure 5-3.
- Air Bags - 28 1/2-inch flat diameter bag with a 2-inch diameter vent hole. Bag is constructed of 840 denier, neoprene-coated 24 warp x 24 fill nylon.
- Deployable Cover - Urethane injection molded part having an H-pattern split line on the underside, see Figure 5-4.
- Steering Wheel - Volvo GT sport wheel; see Figure 5-5 for driver air bag assembly details.

Weights of the components for the driver air bag system have been summarized in Table 5-2.

Table 5-2

DRIVER AIR BAG COMPONENT WEIGHTS

Component	Vehicle Weight, lbs.
Volvo GT Sport Wheel (3.9 lbs.)	-.20 (replaced Simca wheel weighs 4.1 lbs.)
Inflator	3.48
Air Bag	.72
Manifold Box	1.30
Cover	.60
Assembly Hardware	.91
	6.81 lbs.

Dimensions In Inches

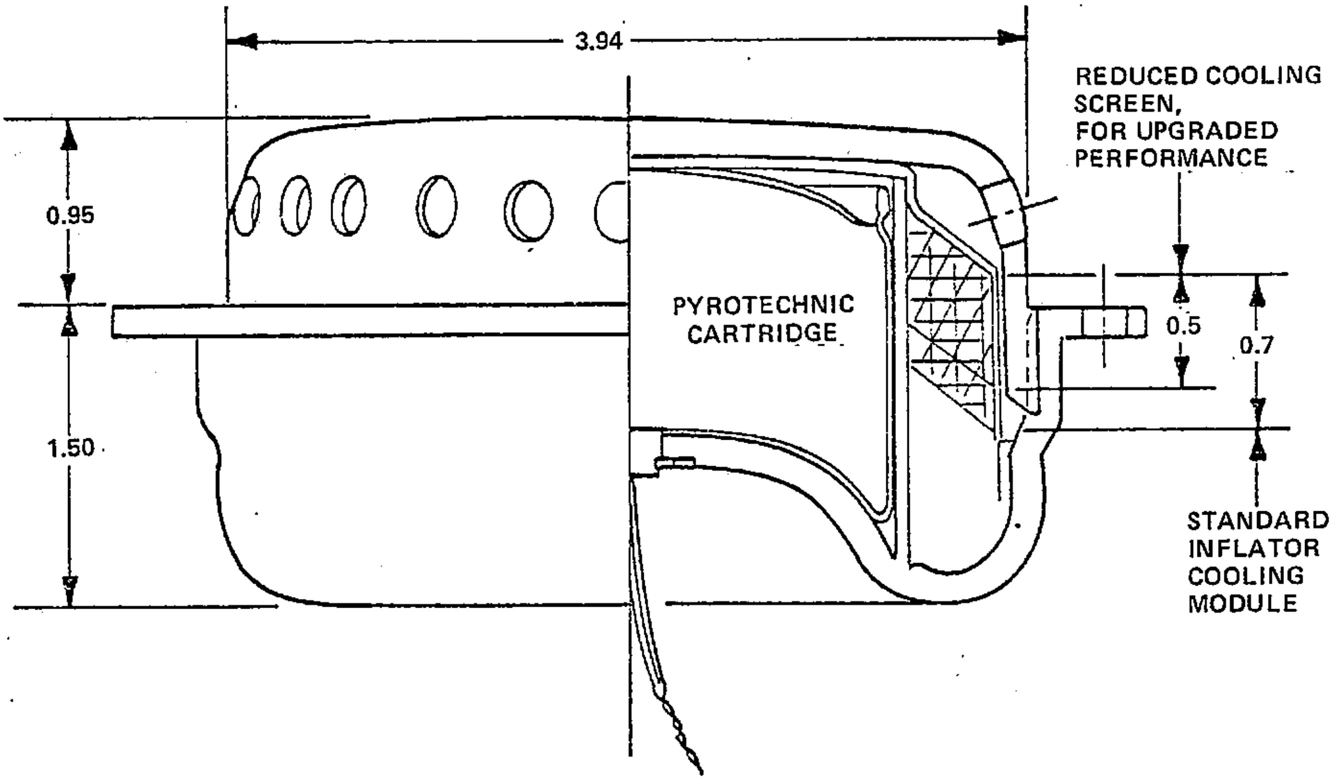


Figure 5-3 THIOKOL CORP. DRIVER AIR BAG INFLATOR

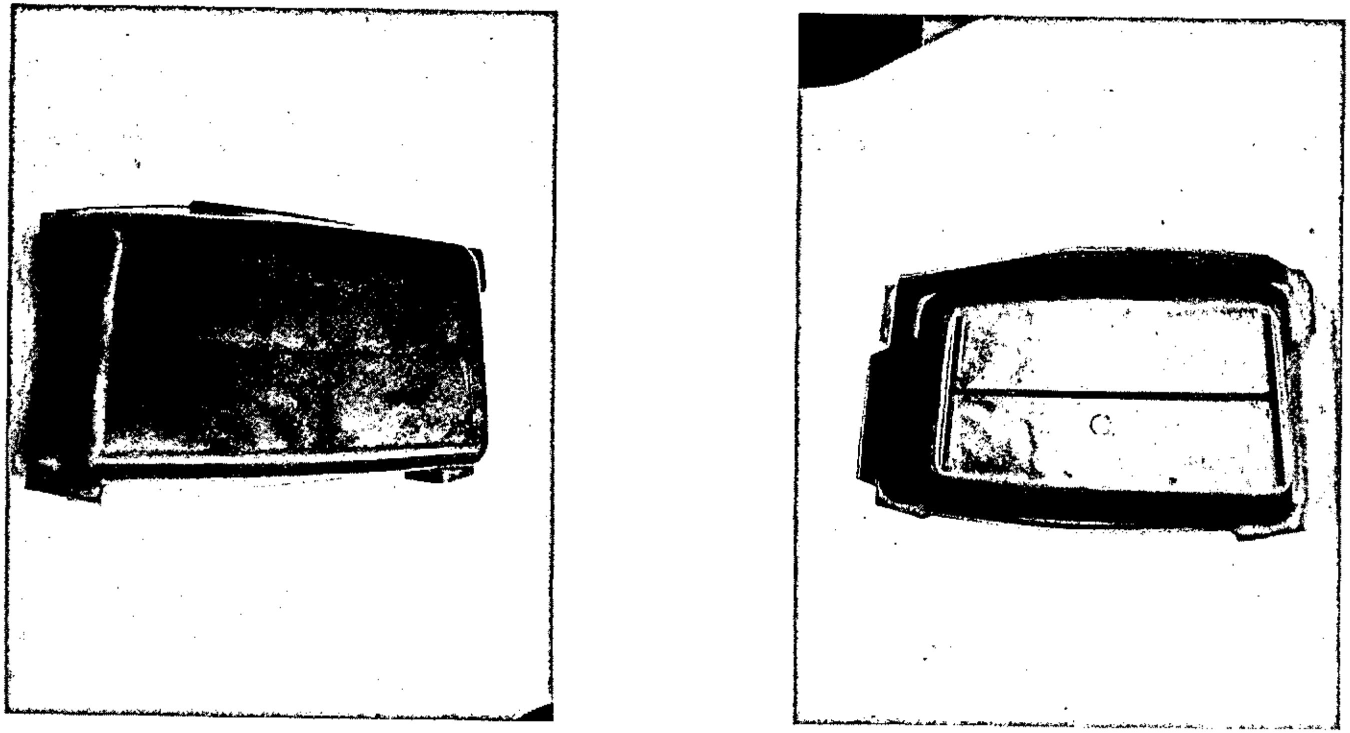


Figure 5-4 DEPLOYABLE DRIVER AIR BAG COVER (AS OBTAINED OFF THE MOLD, PRIOR TO TRIMMING)

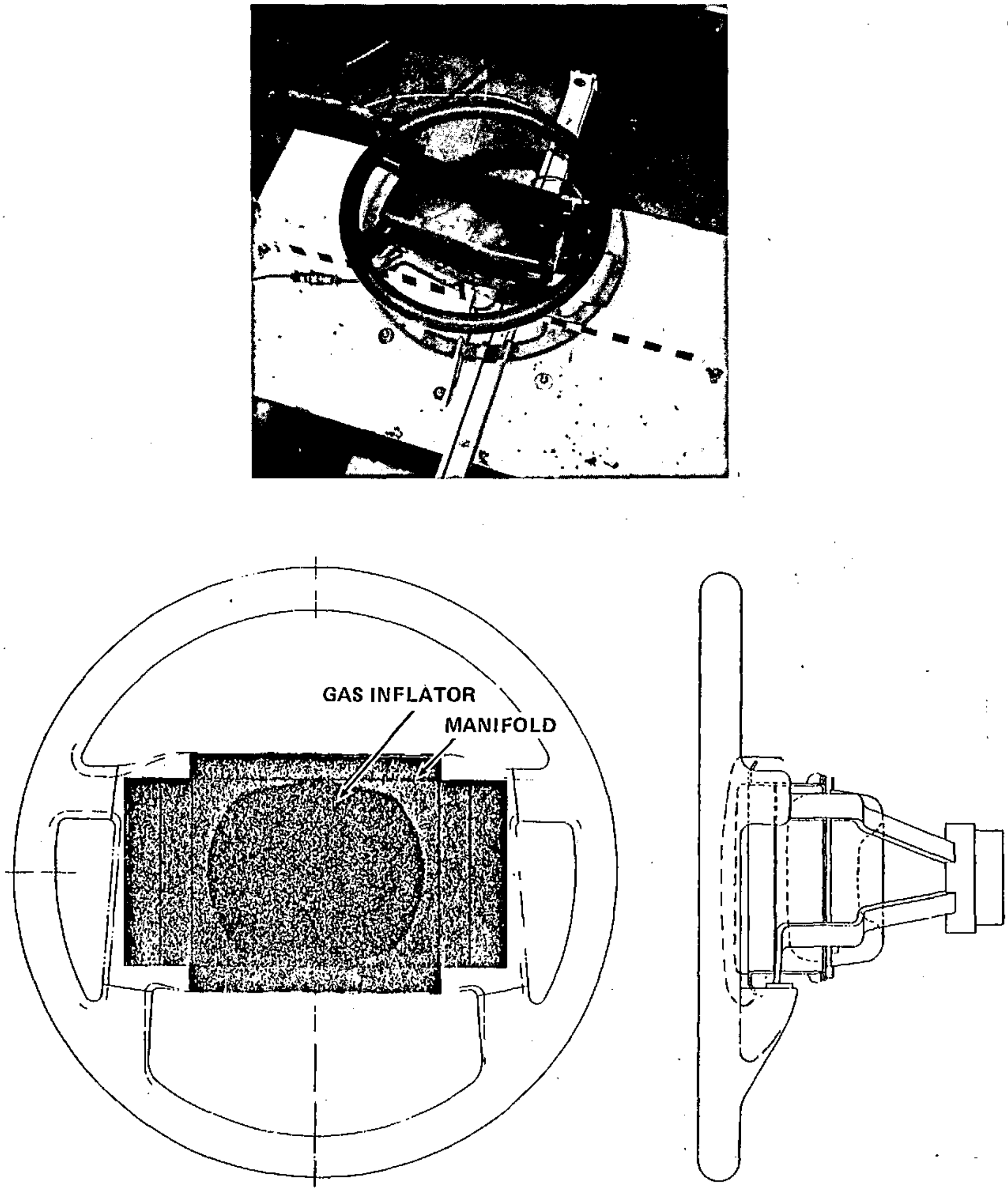
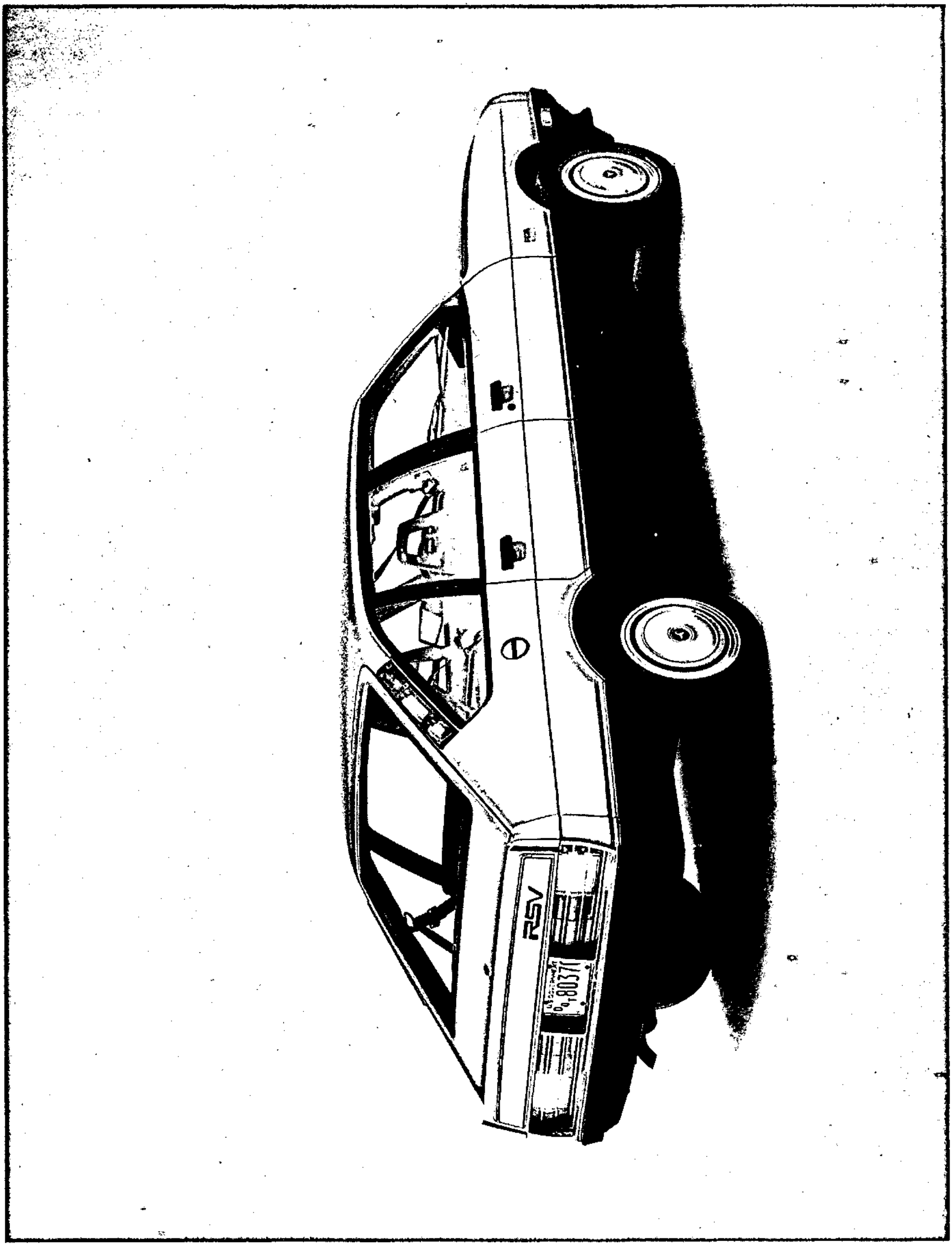


Figure 5-5 ASSEMBLY DRIVER AIR BAG

Photos of the Calspan/Chrysler Phase IV RSV build cars with the installed driver air bag system are presented in Figures 5-6 through 5-10.

Figure 5-6 SIDE VIEW OF RSV

Figure 5-7   ANGLED FRONT VIEW OF RSV



Fi[illegible] 5-[illegible]. ANGLED REAR VIEW OF RSV

Figure 5-9 INTERIOR VIEW OF RSV

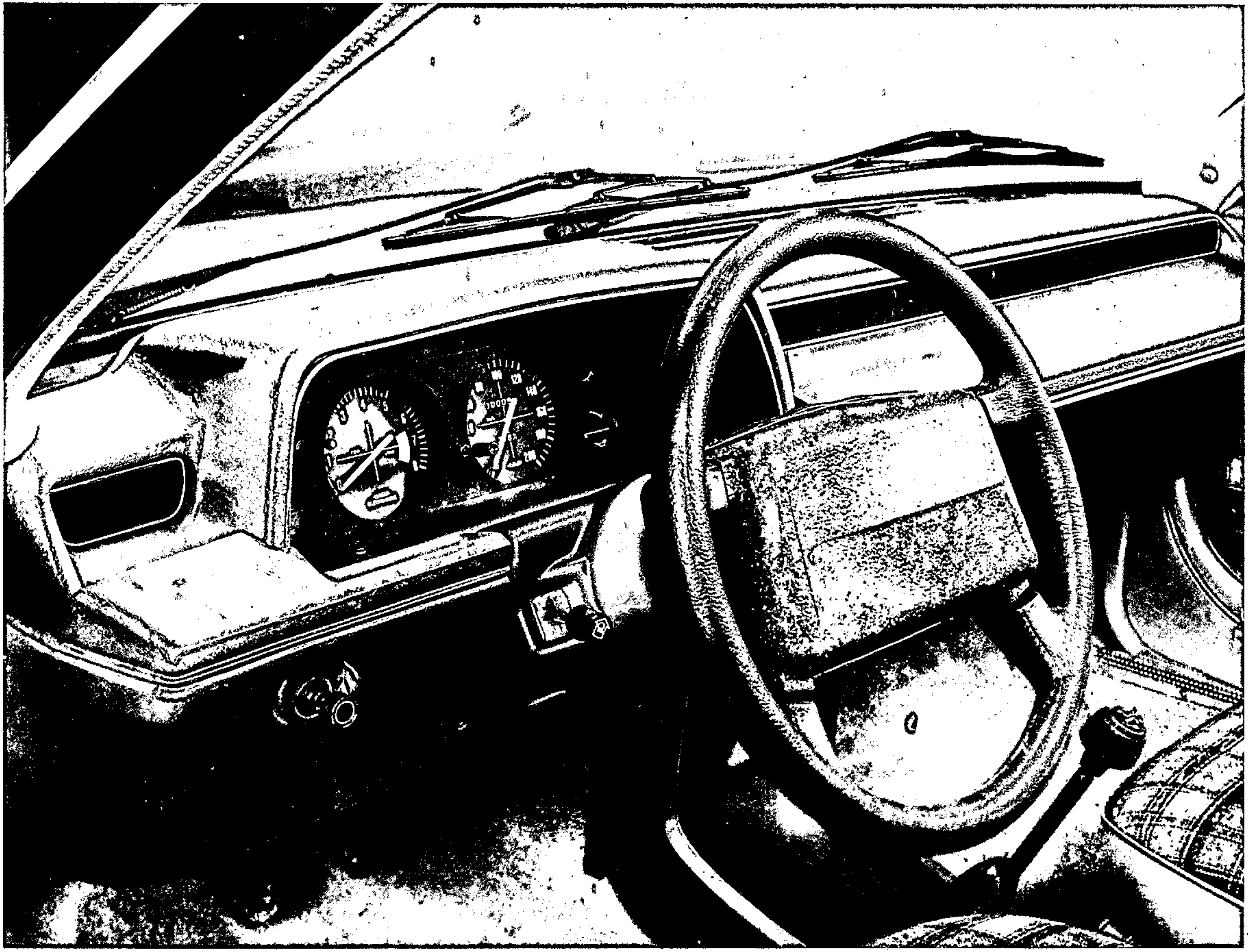


Figure 5-10   RSV DRIVER AIR BAG SYSTEM

6.0 EVALUATION SLED TESTS

Once the final design was established, a series of sled tests was performed to evaluate the system performance for a number of parameters. Final design components were used exclusively; i.e., bag, column, instrument panel, seats, etc. Variables examined were occupant size, sled speed, seat position (full forward, mid or normal, and full rear), sled angle, and the effect of lap belt use.

6.1 50th Percentile Male Results

Aligned Sled Tests

Eight sled runs were performed with a 50th percentile male to evaluate driver performance during a head-on exposure. Data obtained from these tests have been summarized in Table 6-1. HIC numbers and chest resultant accelerations for these tests are graphically represented in Figures 6-1 and 6-2. Selected Polaroid eight-shot sequence pictures and post-test photos of the restraint components are provided in Figures 6-3 through 6-6. Results are discussed in terms of test parameters in the ensuing paragraphs.

Velocity Dependency

Sled Tests 1892, 1893, 1895 and 1899 were performed at 35.3, 40.2, 45.1 and 47.6 MPH using a 50th percentile male-sized dummy in the mid-seat or baseline position. Figure 6-3 depicts dummy kinematics and a post-test photo of the collapsed wheel and the aluminum honeycomb knee restraint insert for the 45 MPH exposure, Test 1895.

All the injury criteria were satisfied in the first three dummy exposures. At 45.1 MPH the HIC number was 505 and the chest resultant acceleration was 53 g's. However, the chest resultant acceleration for the 47.6 MPH exposure, Test 1899, exceeded the 60 g limit. The sum of available

Table 6-1

RSV PERFORMANCE EVALUATION DRIVER AIRBAG SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA								RESTRAINT DATA					
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION					
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.	BAG SIZE / VENT	LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	BAG PRESSURE (psig)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)	
11/4	1892	35.3	27.6	27.5	NO ROOF	28.5" 2.0	NO	50th	MID	39 (74)*	480	362	44	400	74	1600	1560	2.9	2.2	7.0	–	–	(1)
11/7	1893	40.2	29.9	35.2	NO ROOF	28.5" 2.0	NO	50th	MID	42 (90)	560	394	42	420	74	2000	1150	2.5	3.5	7.5	–	–	
11/8	1894	45.0	35.4	38.4		28.5" 2.0	NO	50th	MID	80	1600	950	72	1130	82	1700	1700	3.5	3.0	–	–	–	(2)
11/9	1895	45.1	34.4	38.4		28.5" 2.0	NO	50th	MID	51	660	505	53	510	88	1500	1600	4.5	3.5	9.5	–	–	
11/10	1896	45.2	35.1	37.0		28.6" 2.0	YES	50th	MID	50	700	573	46	520	82	1530	1100	4.0	3.0	–	775	3.0	
11/11	1897	45.7	33.9	38.9		29.5" 2.0	NO	50th	REAR	74	960	701	53	660	74	2600	1550	4.5	4.7	–	–	–	(3)
11/14	1898	46.1	34.9	38.4		28.5" 2.0	NO	50th	FORWARD	59	780	503	53	650	55	1700	1700	4.2	3.5	9.5	–	–	
11/15	1899	47.6	37.4	37.6		28.5" 2.0	NO	50th	MID	86	1320	994	81	1240	80	1750	1700	4.5	3.7	11.0	–	–	

(1) HEAD HIT WINDSHIELD
(2) RETAINING WASHER IN STEERING COLUMN OMITTED
(3) DRIVER CAME OFF SEAT

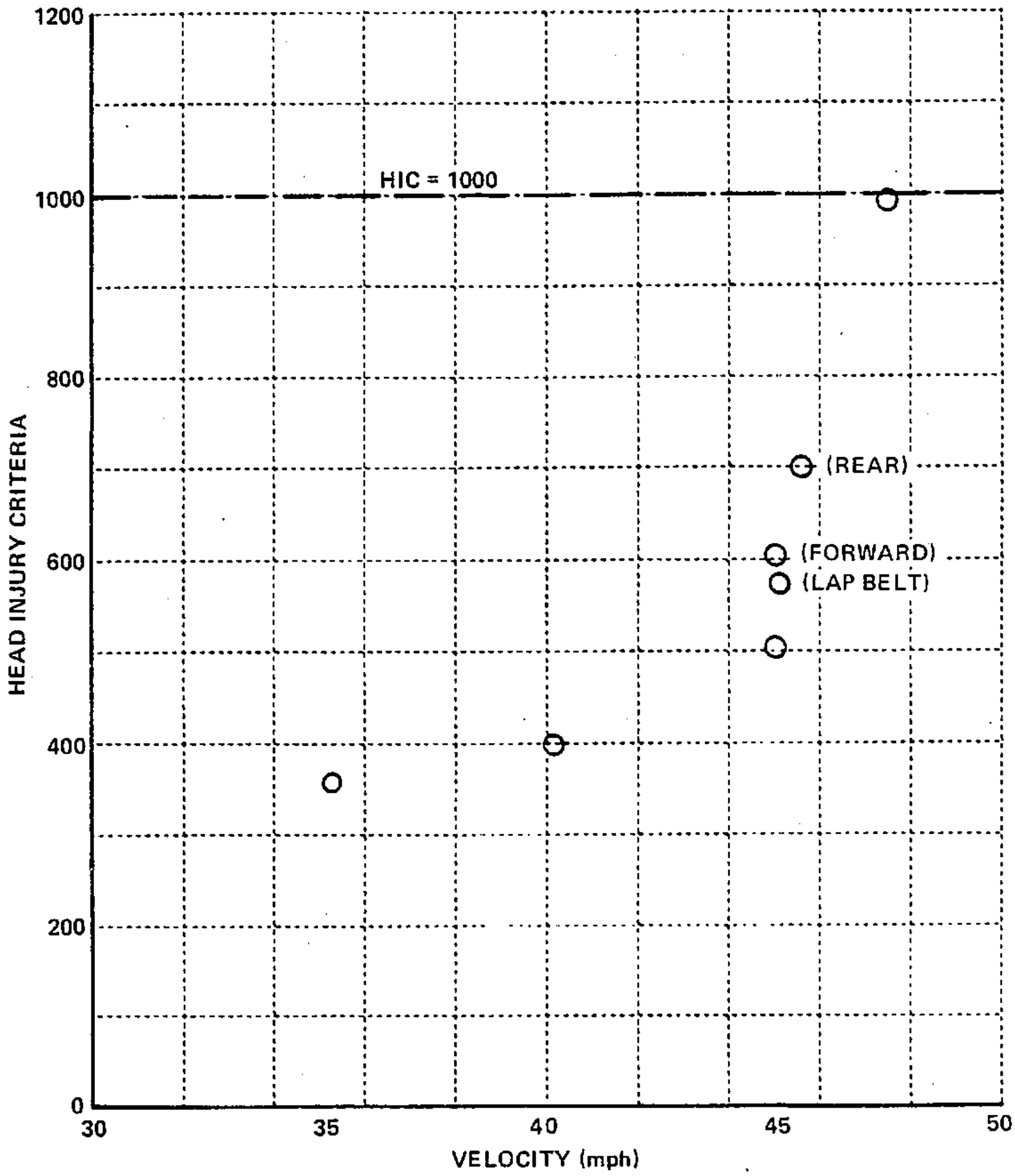


Figure 6-1 DRIVER AIR BAG EVALUATION; SLED TEST RESULTS (50th PERCENTILE MALE)

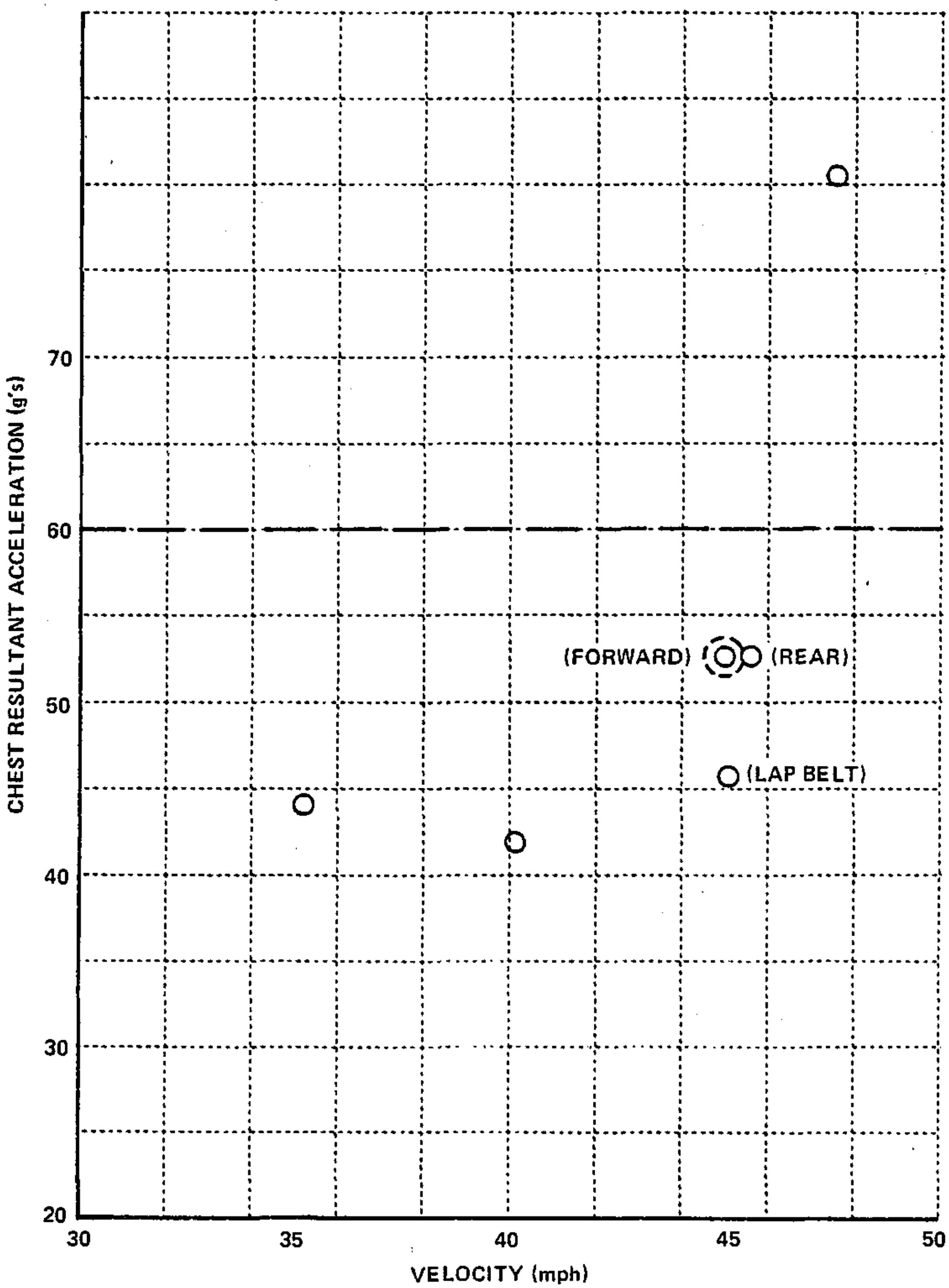
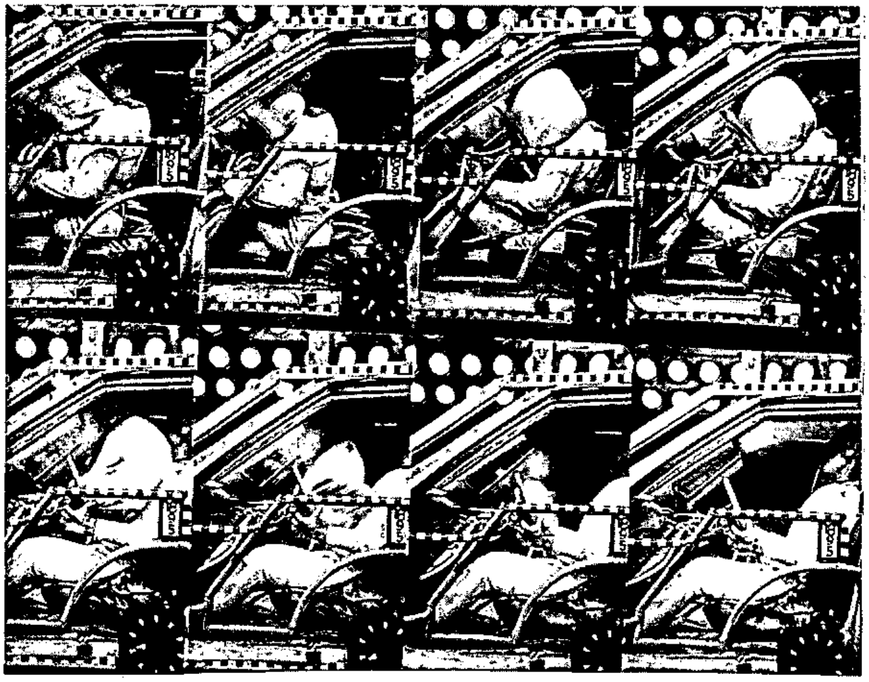


Figure 6-2 DRIVER AIR BAG EVALUATION; SLED TEST RESULTS (50th PERCENTILE MALE)



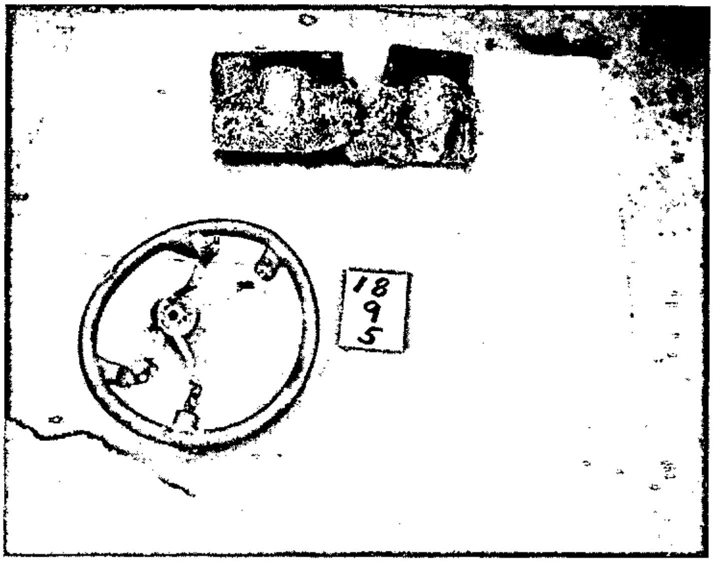


Figure 6-3 TEST 1895 PHOTOS (45 MPH, MID SEAT POSITION)

stroke in the bag, wheel, and steering column was exhausted. Thus the upper limit of performance is between 45.1 and 47.6 MPH.

Seating Position Sensitivity

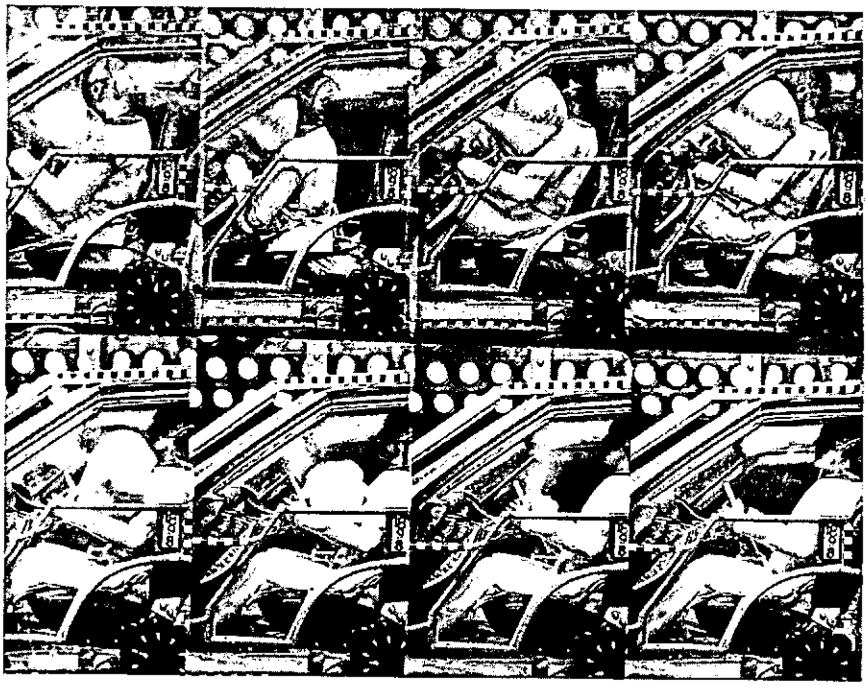
A measure of the potential degradation in dummy performance with respect to positioning of the front seat, was also obtained as part of the evaluation series. In addition to Run 1895, 45.1 MPH with the seat in the normal mid-position, two other tests were performed at 45.1 and 45.7 MPH with the front seat located in the full forward (Test 1898) and full rear positions (Test 1897). Pictures for these tests are provided in Figures 6-4 and 6-5. The allowable RSV seat track travel is five inches. Thus, these two exposures examined the sensitivity of dummy positioning ± 2.5 inches from the baseline.

The chest resultant accelerations were identical in all three cases, 53 g's, while HIC numbers varied from 505 for the mid seat test to 701 for the full rear position demonstration.

For the 45.7 MPH test with the seat in the rear position, the dummy translated forward to the front edge of the seat and came off as he began to rebound. Because this occurred late in the test, dummy responses were not adversely affected. Viewed in this perspective, the kinematics were acceptable. Furthermore, this might not have occurred if a new seat had been available since the front portion of the RSV seat cushion frame structure was weak due to repetitive testing. As such, the vertical support and horizontal resistance supplied by the front seat edge were less than optimum.

In view of the similarity of results obtained for the dummy injury measures, it does not appear that significant degradation of performance occurs with the 50th percentile dummy for the range of available seating positions in the 45-46 MPH velocity interval.

150 117 56 51



27 23 18

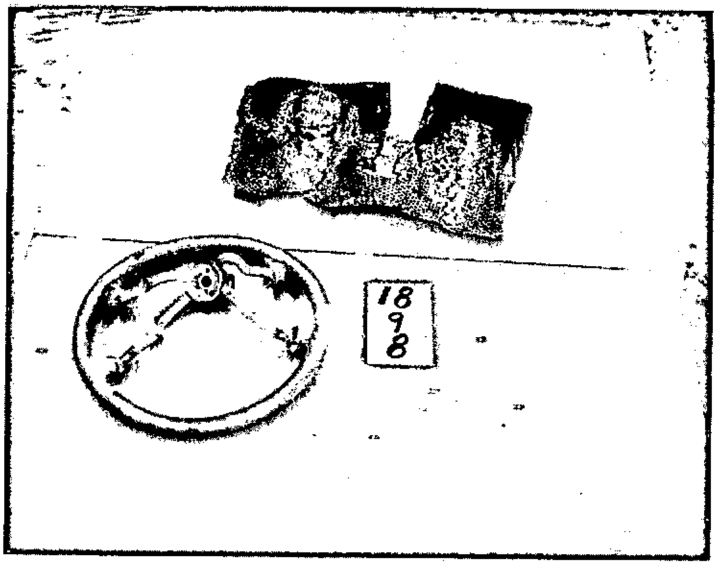
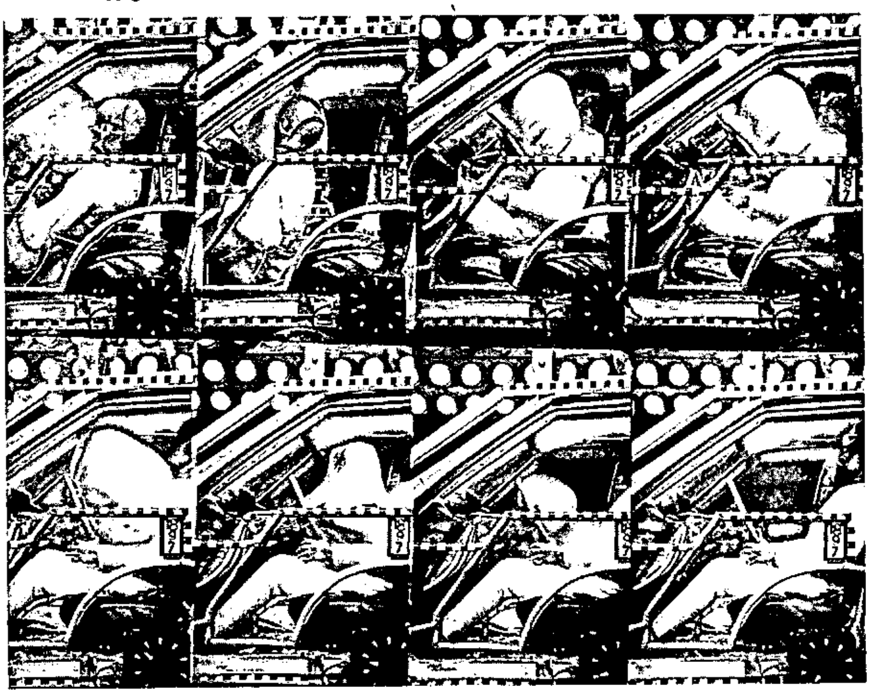


Figure 6-4 TEST 1898 PHOTOS (45 MPH; SEAT FULL FORWARD)

176 119 56 50



33 23 17 7

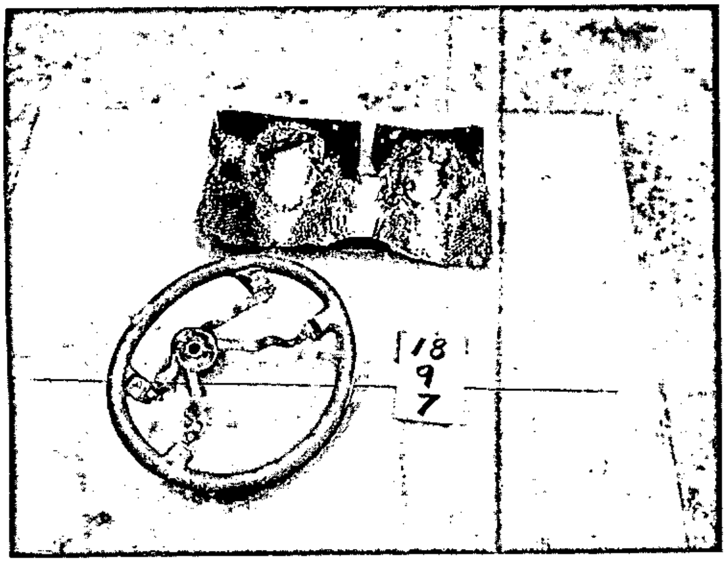


Figure 6-5 TEST 1897 PHOTOS (45 MPH; SEAT FULL REAR)

Lap Belt Sensitivity

The effects of lap belt use were also investigated. Test 1896 (see Figure 6-6) was performed at 45.2 MPH with a lap belted 50th percentile dummy in the normal mid-seat position. Results of this test appear in Table 6-1. The injury criteria were all met as illustrated in Figures 6-1 and 6-2. The chest resultant acceleration was 46 g's, while the HIC number was 573. When compared to the unbelted case, Test 1895, it appears that lap belt use resulted in a slight improvement in chest response.

Angled Sled Tests

Upon completion of the aligned sled tests, four angled sled tests were performed with the 50th percentile driver in the mid-seat position. Since the buck could not easily accommodate a positive angle rotation, the passenger position was modified to accept the installation of a steering column. Thus, positive angle tests, i.e., driver translating towards the A pillar, were simulated by using the driver installation on the right hand side of the buck. This precluded the use of the Phase III instrument panels. For reasons of consistency in all of the angled tests, Phase III developmental test knee restraints were utilized for both positive and negative angle demonstrations. Tests were performed with the sled buck rotated at both -12° and -20°. For the positive angle exposures, a Phase III RSV door was installed on the right hand side of the buck.

Lastly, the sled pulse was modified to reflect the lower deceleration response that would be experienced in an angled barrier test. It was estimated that the peak frontal barrier compartment acceleration would be reduced by one-third and the pulse duration increased by about fifty percent in an angled impact. Figure 6-7 compares a typical RSV 45 MPH aligned sled pulse with that used in an angled test.

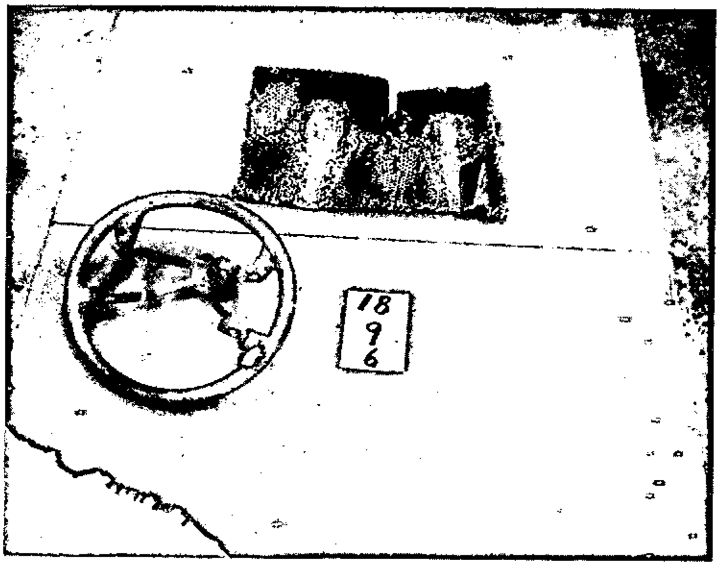


Figure 6-6 TEST 1896 PHOTOS (45 MPH; LAP BELT, MID SEAT)

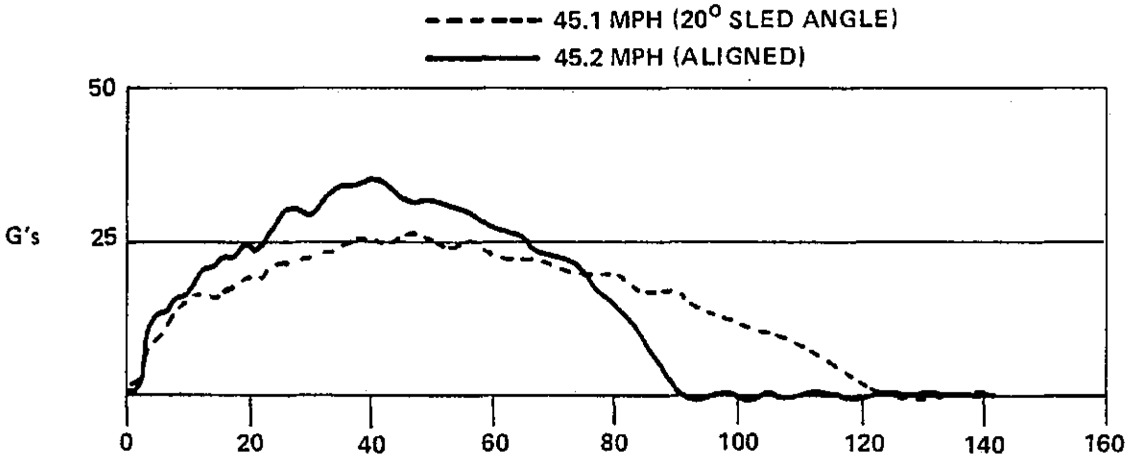


Figure 6-7 COMPARISON OF TYPICAL 45 MPH RSV SLED PULSES

Results of the angled sled test runs are summarized in Table 6-2 and graphically presented in Figures 6-8 and 6-9. Dummy kinematics and a post-test photo of the wheel, steering column shaft, and aluminum honeycomb insert for the knee restraint for test 1912 (+12° at 45 MPH) are illustrated in Figure 6-10. Very acceptable results were obtained for both the injury criteria and dummy kinematics for all four runs, i.e., +12° at 39.3 MPH, +12° at 44.7 MPH, +20° at 45.1 MPH, and -20° at 45.1 MPH. The highest chest resultant acceleration recorded was 45 g's for both the +12° and -20° runs at 45 MPH, while the highest value for the HIC number was 540 for the +20° test at 45 MPH.

The mild exposures experienced in these sled runs are a reflection of the milder sled pulse used in conjunction with the angled tests. Lateral torso restraint provided by the RSV inner door panel also aided the dummy response by minimizing potential head to A pillar contact.

6.2 Summary of the Evaluation Testing Results for the 50th Percentile Dummy

Encouraging results were obtained for the RSV driver air bag system in the evaluation sled test series. Acceptable performance was demonstrated at speeds in excess of 45 MPH for each of the following conditions:

- normally seated
- normally seated with lap belt
- full forward seating position
- full rear seating position
- +12° angled exposure
- +20° angle exposure
- -20° angle exposure.

Table 6-2

RSV PERFORMANCE EVALUATION
DRIVER AIRBAG
ANGLED SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA									RESTRAINT DATA					
										HEAD			CHEST		PELVIS	FEMUR LOAD, lbs		KNEE BAR PENETRATION		BAG PRESSURE (psig)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.	BAG SIZE / VENT	LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)			
12/15	1911	39.3	21.3	51.6	+12° (Driver Rt.)	28.5" / 2.0"	NO	50th	MID	43	360	273	44	340	62	1480	1590	1.9	1.6	6.3	–	–
12/16	1912	44.7	25.2	53.7	+12° (Driver Rt.)	28.5" / 2.0"	NO	50th	MID	64	560	430	45	380	–	1950	1950	1.9	2.0	8.0	–	–
12/21	1915	45.1	26.3	55.0	+20° (Driver Rt.)	28.5" / 2.0"	NO	50th	MID	69	890	540	42	460	80	2500	1680	2.5	2.0	6.5	–	–
12/22	1916	45.1	25.9	55.1	-20° (Driver Left)	28.5" / 2.0"	NO	50th	MID	40	410	322	45	360	64	1630	2000	1.7	1.7	7.4	–	–

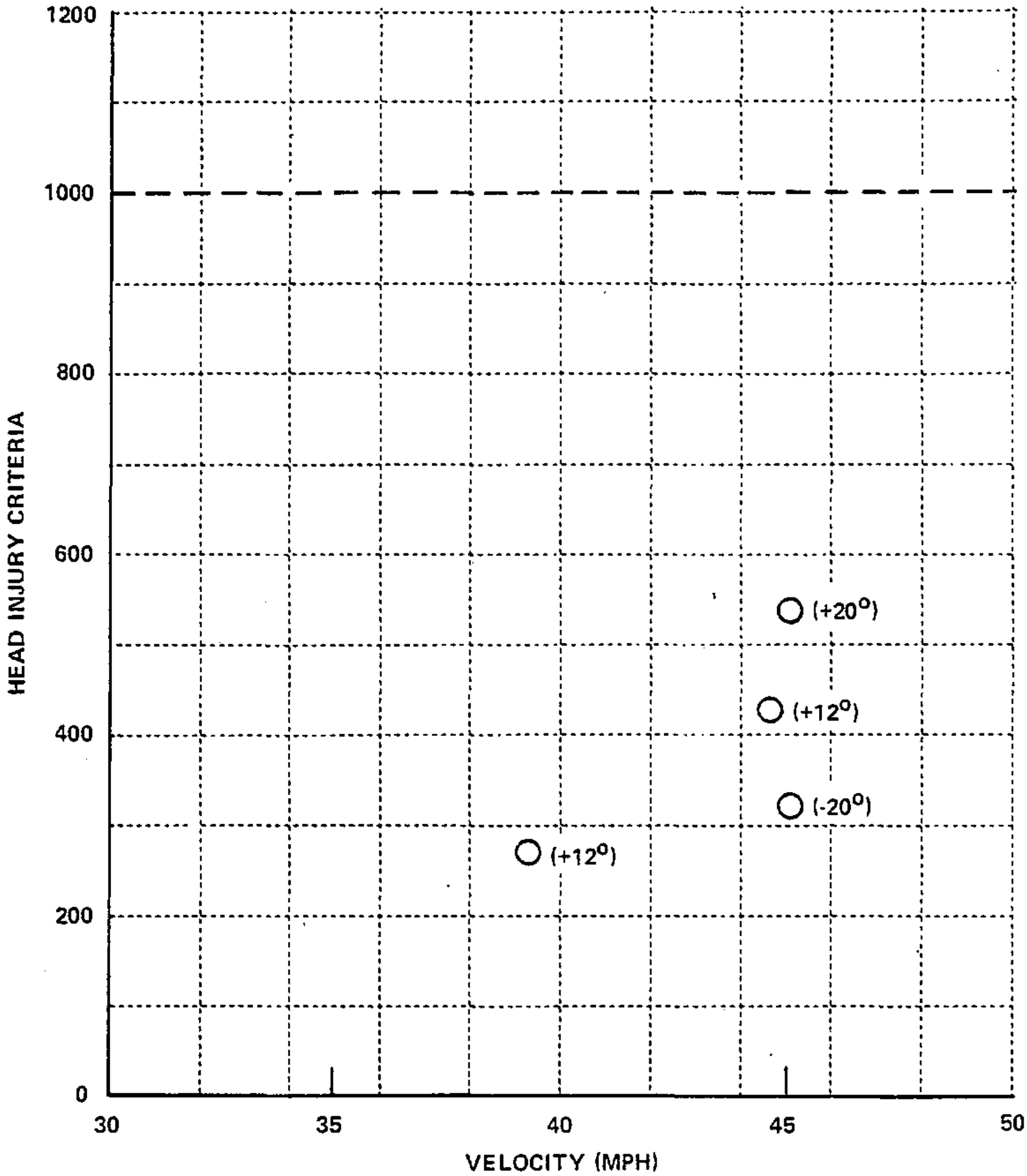


Figure 6-8 DRIVER AIR BAG EVALUATION; ANGLED SLED TEST RESULTS (50 th PERCENTILE MALE)

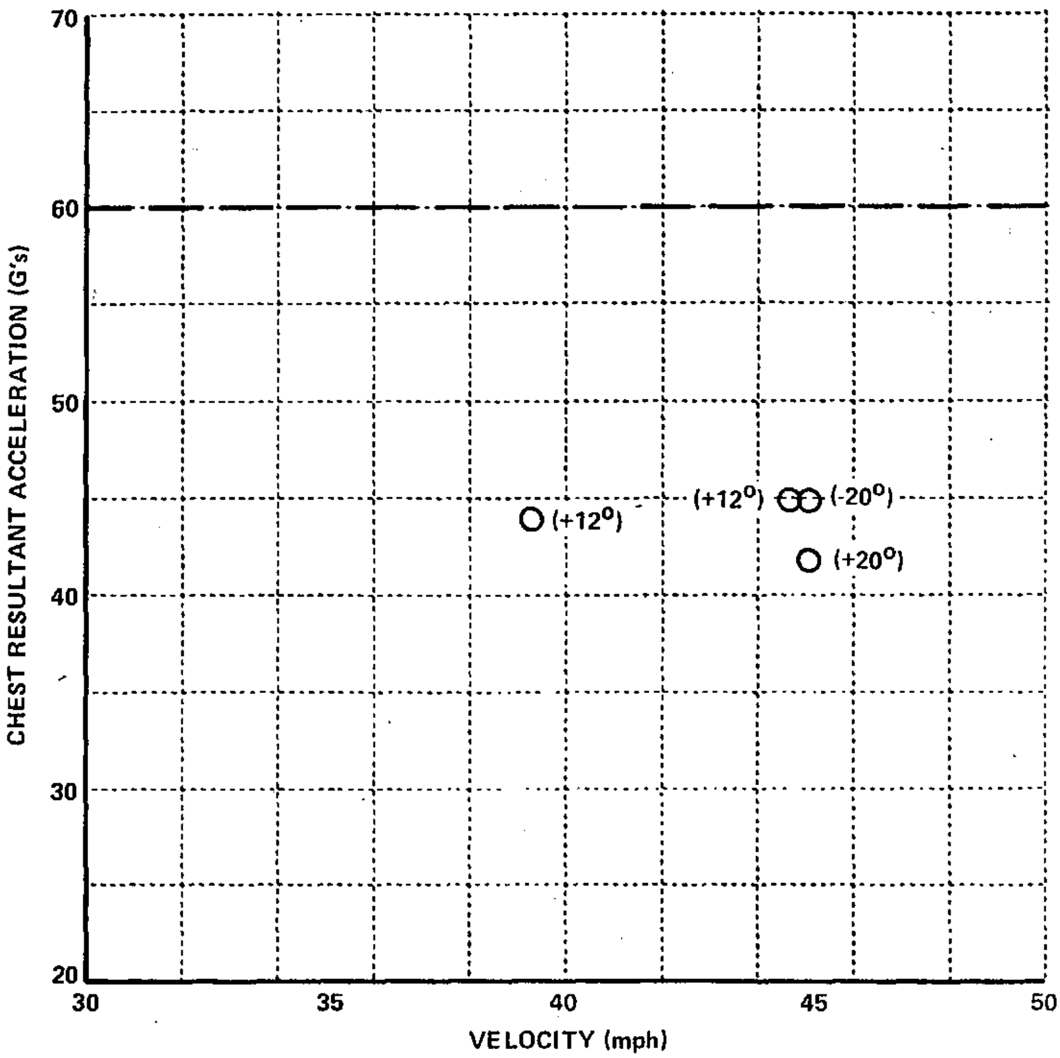


Figure 6-9 **DRIVER AIR BAG EVALUATION; ANGLED SLED TEST RESULTS (50th PERCENTILE MALE)**

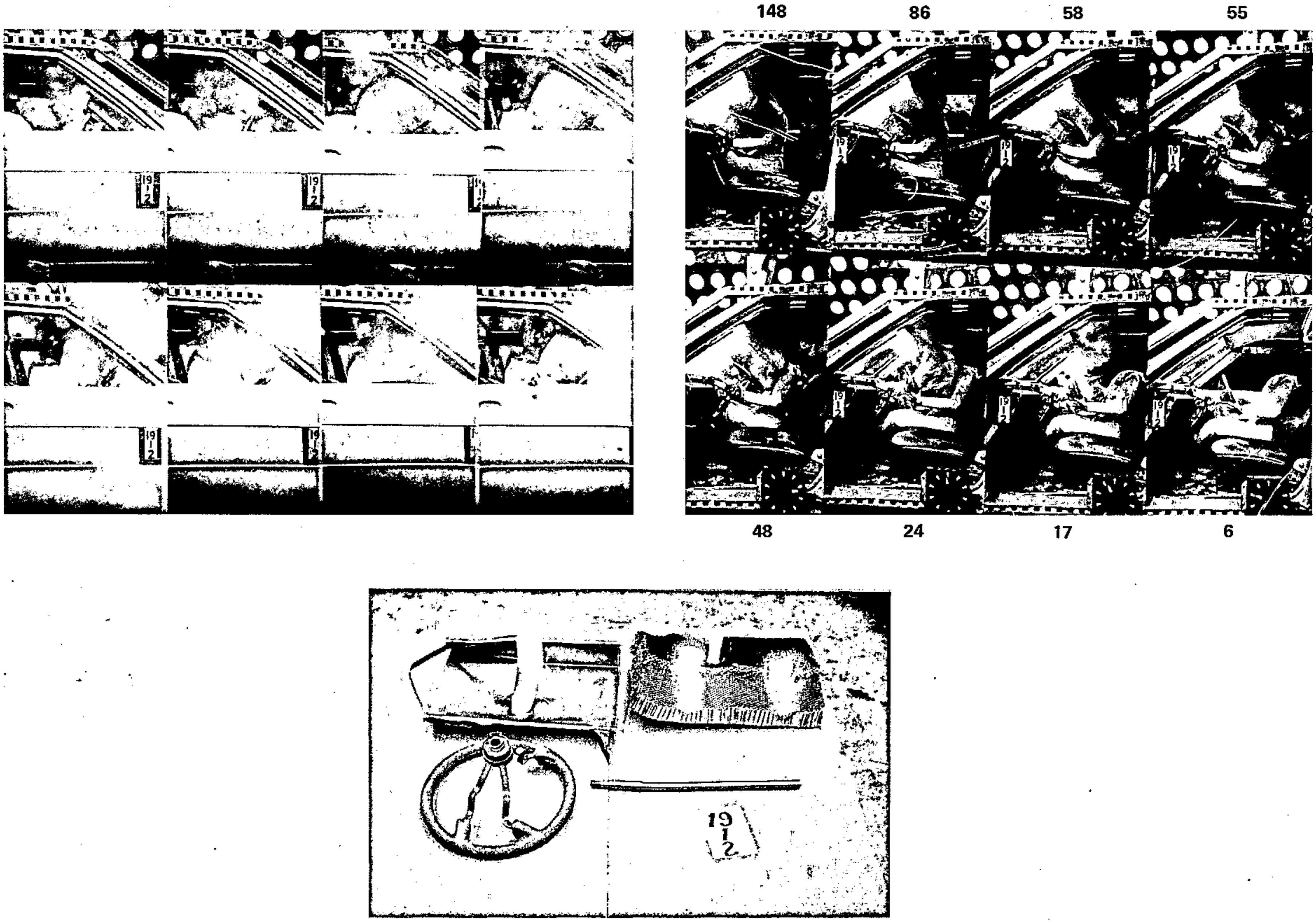


Figure 6-10   TEST 1912 PHOTOS (45 MPH; +12° SLED ANGLE)

Fifty-three g's and 703 were the maximum values recorded for the chest resultant acceleration and HIC number in the 45 MPH tests listed above. Satisfactory dummy kinematics and HIC results were obtained at 47.6 MPH for the normally seated condition; however, the chest resultant acceleration response was unacceptable. In the developmental sled test series, using the stiffer knee restraint, satisfactory results had been obtained at 47.5 MPH (sled Test 1843). Data for that test appear in Table 4-2.

Thus, the upper limit of acceptable performance for the normally seated 50th percentile male dummy is certainly above 45 MPH and is probably close to 47 MPH.

6.3 Non-50th Percentile Results

The non-50th percentile testing consisted of eight sled runs; four driver exposures for the 5th percentile female dummy size, and four runs for the 95th male. Results of these tests are summarized in Table 6-3, and the injury criteria are graphically represented in Figures 6-11 and 6-12.

5th Percentile Female

Performance of the 5th percentile female driver was evaluated at 35, 40 (with and without a lap belt) and 43 MPH (Tests 1876, 1883, 1877 and 1879 in Table 6-3). Polaroid eight-shot sequence and post-test photos of the wheel and aluminum honeycomb insert for the RSV instrument panel are presented in Figure 6-13 (40 MPH exposure, Test 1877).

Dummy kinematics were satisfactory in all four cases. All the injury criteria were satisfied for the 5th percentile female sized dummy at 35 MPH (Test 1876) and at 40 MPH (Tests 1877 and 1883). An active lap belt with a nominal load limiting level of 750 lbs. was employed in one of the two 40 MPH demonstrations (Test 1883). Head results were improved while the chest response was degraded with lap belt use. (Compare Run 1883 to the unbelted case - Run 1877). Nevertheless, there were no significant differences in

Table 6-3

RSV PERFORMANCE EVALUATION DRIVER AIRBAG SLED TEST RESULTS

TEST CONDITIONS						RESTRAINT CONDITIONS		DUMMY		DUMMY DATA: HEAD			DUMMY DATA: CHEST		DUMMY DATA: PELVIS	DUMMY DATA: FEMUR LOAD, lbs		RESTRAINT DATA: KNEE BAR PENETRATION		RESTRAINT DATA		
DATE	RUN NO.	VEL. MPH	MAX G	STROKE	CONFIG.	BAG SIZE / VENT	LAP BELT	SIZE	POSITION	H_R (g's)	HSI	HIC	C_R (g's)	CSI	P_x (g's)	L	R	L (in.)	R (in.)	BAG PRESSURE (psig)	LAP BELT LOAD (lb.)	LAP BELT ELONGATION (in.)
10/11	1876	35.1	27.9	27.8"		28.5" / 2.0"	NO	5%	FORWARD	65	608	646	60	750		1050	1300	1-1/4	1-1/8	4.5	–	–
10/12	1877	40.1	29.8	35.0"		28.5" / 2.0"	NO	5%	FORWARD	88	840	493	48	580		1530	725	1-1/2	1-3/8	5.2	–	–
10/13	1878	43.1	32.9	41.8"		28.5" / 2.0"	NO	5%	FORWARD	70	860	691	74	1000		1580	1250	1-11/16	1-5/16	6.0	–	–
10/14	1879	35.0	28.0	26.8"		28.5" / 2.0"	NO	95%	REAR	175	2000	1719	47	470	80	1300	1680	3	2-7/8	8.0	–	–
10/18	1880	35.0	28.2	26.7"	ROOF & HEADER SKID PLATE ADDED	28.5" / 2.0"	NO	95%	REAR	105	1200	1045	44	390	70	1625	1350	2-7/8	2-3/4	7.0	–	–
10/20	1881	39.9	30.5	36.0"		28.5" / 2.0"	NO	95%	REAR	160	2000	1515	52	520	64	1600	1100	5-3/8	4-7/8	7.5	–	–
10/21	1882	35.0	27.9	27.2"		28.5" / 2.0"	YES	95%	REAR	148	1400	1031	47	400	72	1150	600	3-1/4	2-7/8	7.2	650	4.5
10/24	1883	40.2	29.9	35.0"		28.5" / 2.0"	YES	5%	FORWARD	55	520	443	60	750		1000	700	1-1/2	3-1/8	5.0	750	1.5

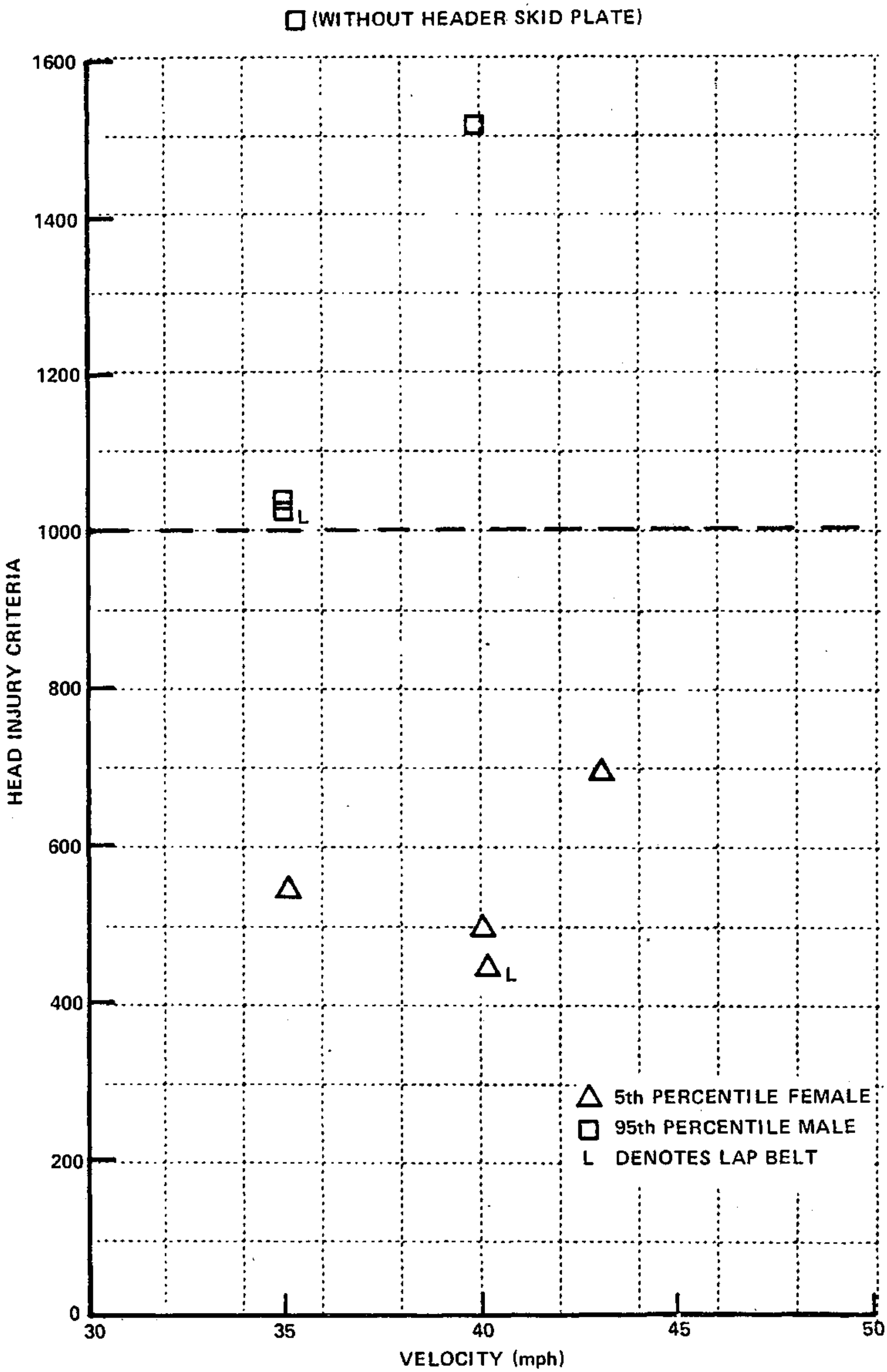


Figure 6-11 DRIVER AIRBAG EVALUATION; SLED TEST RESULTS (5th PERCENTILE FEMALE; 95th PERCENTILE MALE)

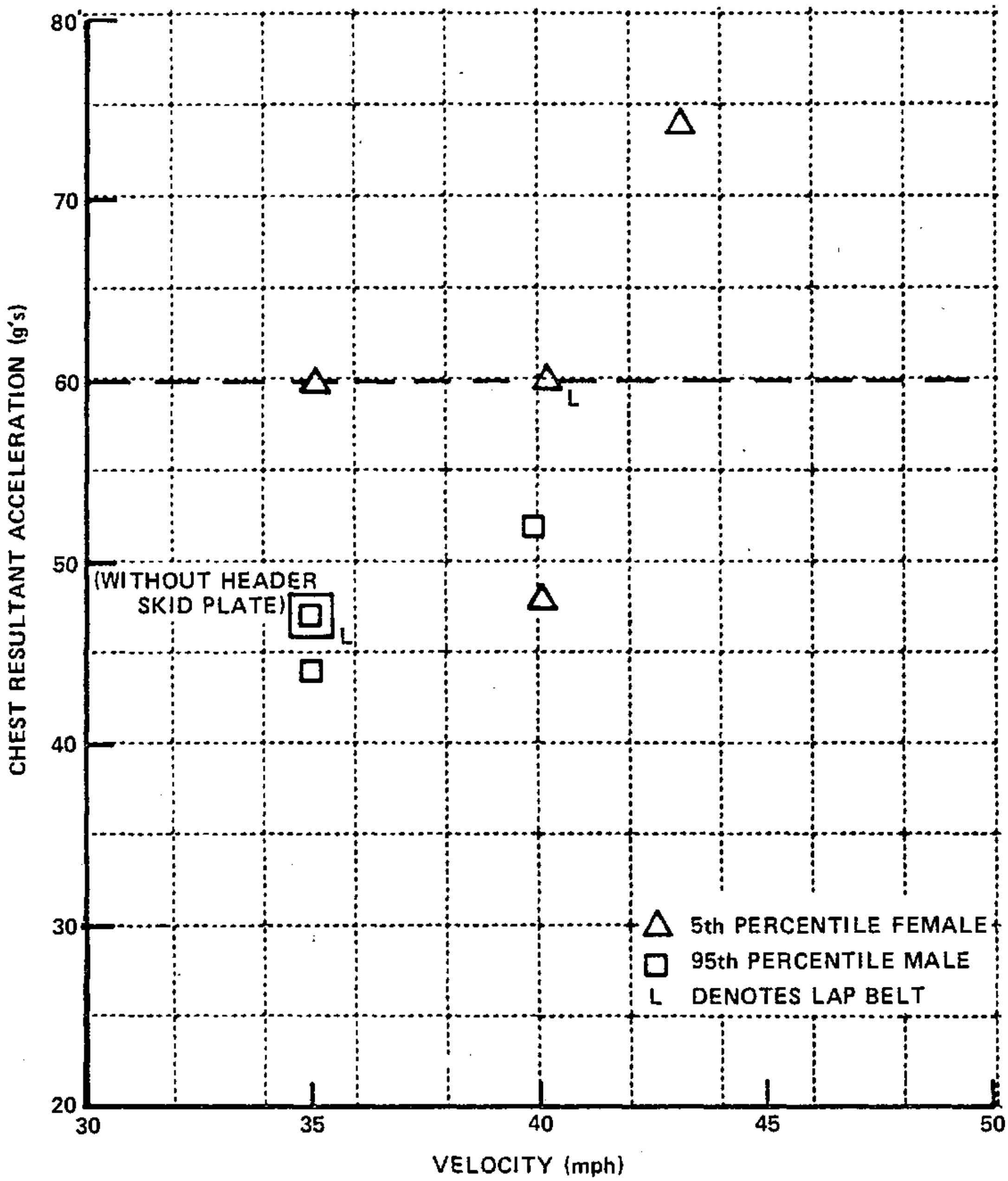
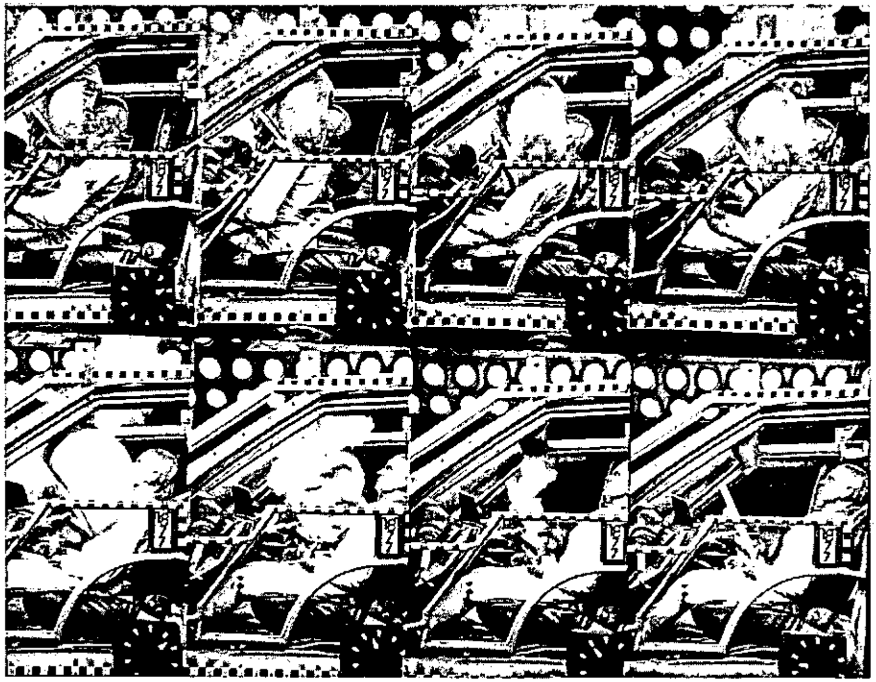
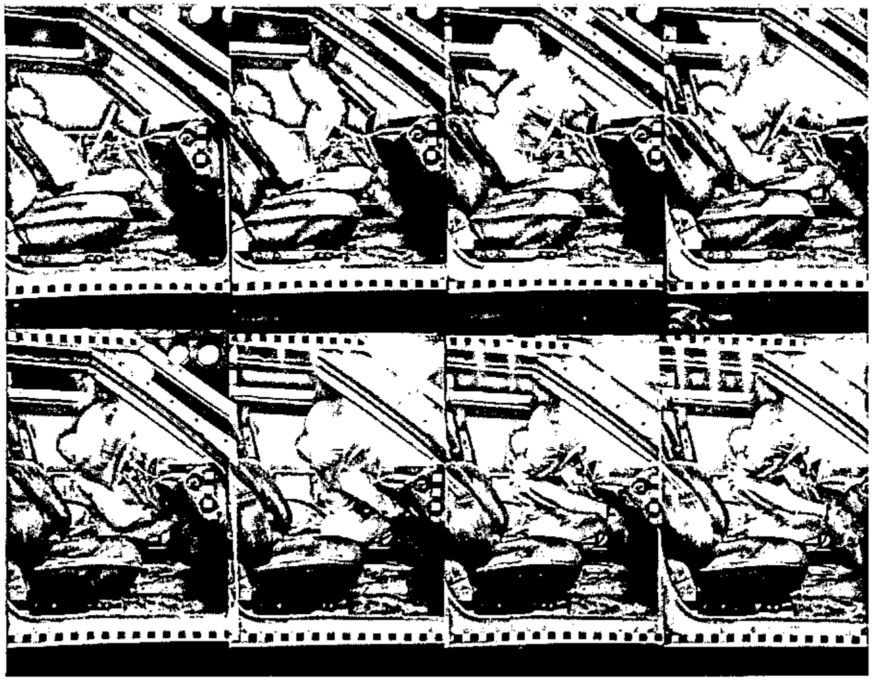


Figure 6-12 DRIVER AIRBAG EVALUATION; SLED TEST RESULTS (5th PERCENTILE FEMALE; 95th PERCENTILE MALE)

(145) (115) (57) (49)



(40) (21) (15) (0)



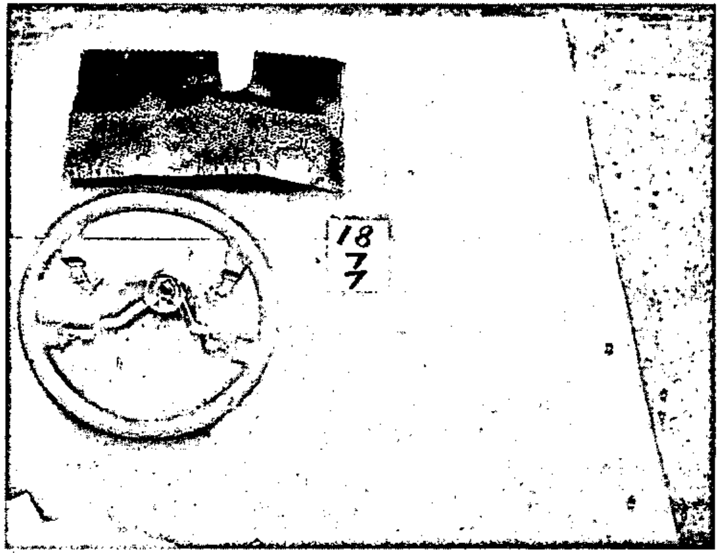


Figure 6-13 TEST 1877 PHOTOS (40 MPH; SEAT FULL FORWARD)

dummy performance and as stated previously all the injury criteria were satisfied for both tests at 40 MPH.

Data were also obtained for a 43 MPH test with the 5th percentile dummy (Test 1878). The injury criteria were acceptable except for the chest resultant acceleration (74 g's). Based upon these test results, it appears that the RSV driver air bag can provide acceptable performance for the 5th percentile female in the 40 to 43 MPH frontal impact speed range.

95th Percentile Male Sled Tests

Four performance evaluation sled tests were also conducted with the 95th percentile male dummy. Three of these tests were conducted at 35 MPH (Tests 1879, 1880 and 1881) and one at 40 MPH. Polaroid eight-shot sequence pictures of test number 1880, the 35 MPH exposure, are presented in Figure 6-14 along with post-test photos of the wheel and aluminum honeycomb instrument panel insert.

In the first 35 MPH sled test (Run 1879), dummy head contact occurred with the front edge of the header resulting in excessive head deceleration (see Table 6-3). Urethane padding had been installed in the sled buck along the header; however, it was ineffective because the forward roof-line of the RSV is simply too low for the 95th percentile seated dummy. Figure 6-15 depicts the contact area. All the other injury criteria were satisified. For example, the chest resultant acceleration was 47 g's.

In the subsequent test (Run 1880), also conducted at 35 MPH, a header skid plate was added to the sled buck. The skid plate, made of .030 inch mild steel, is illustrated in Figure 6-16. Kinematics were satisfactory, and the head response was significantly improved. The HIC number was 1045. Again, all of the other injury criteria were satisfactory for the runs. The chest resultant acceleration was 44 g's and the femur loads averaged 1470 pounds. The skid plate was used for the remainder of the 95th percentile tests.

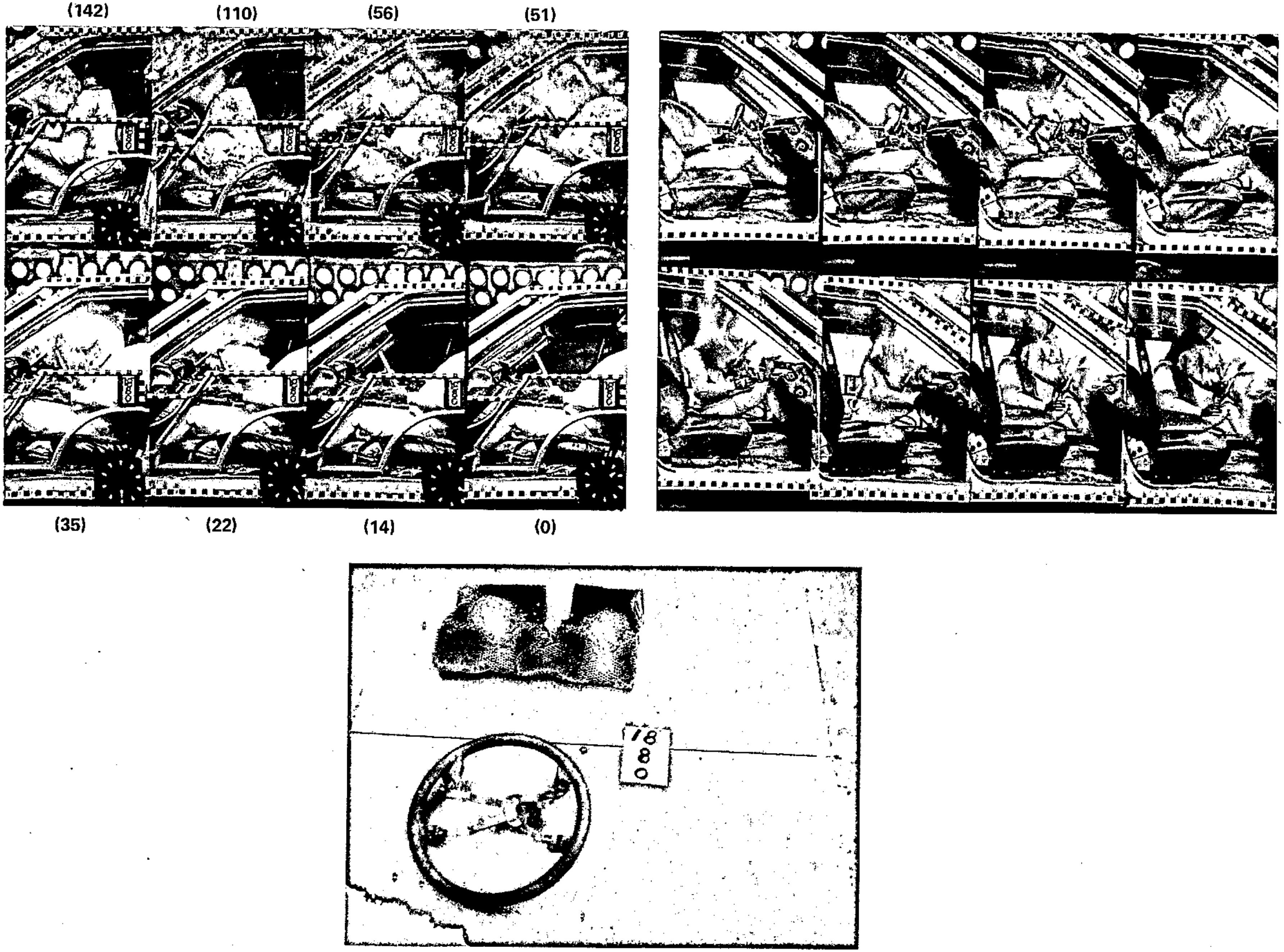


Figure 6-14 TEST 1880 PHOTOS (35 MPH; SEAT FULL REAR; HEADER SKID PLATE)

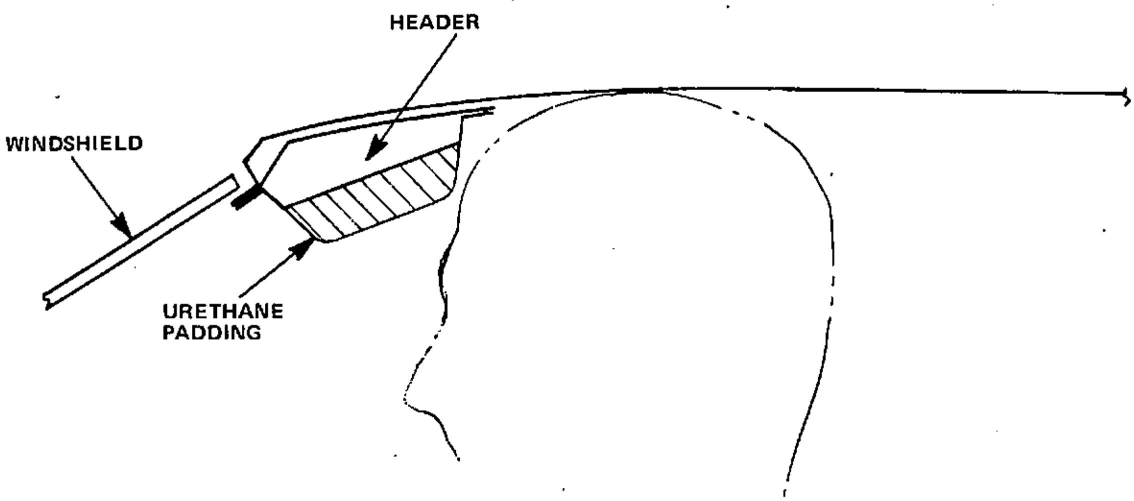


Figure 6-15 HEAD CONTACT AREA FOR 95TH PERCENTILE MALE

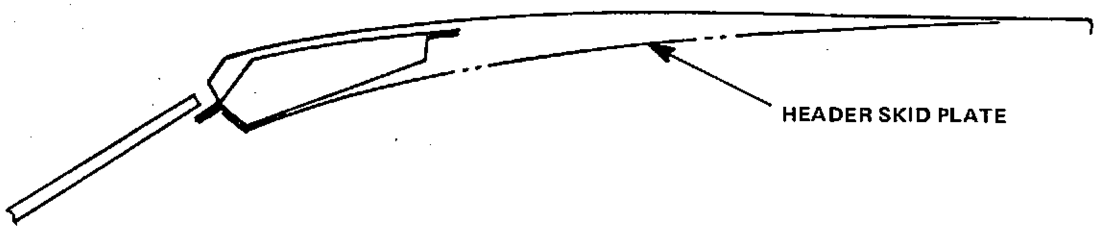


Figure 6-16

Figure 6-16 LOCATION OF HEADER SKID PLATE TO REDUCE 95TH PERCENTILE MALE HEAD CONTACT PROBLEM

The last 35 MPH test (Run 1882) was performed with a lap belt with a limit load of 650 pounds. The HIC number was just over the limit at 1031. There were no appreciable differences between the belted and unbelted results. The chest resultant acceleration was 47 g's and the femur loads averaged 875.

Data were also obtained for a 40 MPH demonstration. A chest resultant acceleration of 52 g's and average femur loading of 1350 pounds were recorded. The head response was unacceptable due to head-header contact.

As a result of these tests, acceptable driver air bag performance can be attained for the 95th percentile male sized dummy at frontal impact speeds just below 35 MPH. Furthermore, it is postulated that satisfactory performance could be achieved in the 40 MPH speed range if it were not for header contact.

7.0 ADDITIONAL INVESTIGATORY STUDIES

As noted previously, the displacement of the RSV steering wheel shaft is upward under occupant loading, as opposed to along the column axis. That factor coupled with the apparent interaction of the dummy torso with the lower steering wheel rim led to two separate studies to ascertain the repeatability of the shaft motion and the magnitude of the potential injury hazard associated with the lower steering wheel rim-to-chest contact. The following two subsections detail those efforts.

7.1 Column Bending

The RSV driver air bag system uses upward column bending as an energy dissipating mechanism instead of column stroking along the shaft axis. As a means of assessing the repeatability of this collapse mode, post test static measurements of steering column deflection were taken for each of the performance evaluation sled tests.

The results have been summarized in Table 7-1. The data, appearing in graphical form in Figure 7-1, indicate that the steering column shaft upward bend angle is proportional to impact velocity for all three occupant sizes (5th, 50th and 95th percentile dummy sizes). Projection of the regression lines suggest that no column bending would occur at speeds below 33 mph for the 5th percentile female and 28 mph for both the 50th and 95th percentile male dummies.

These same data were utilized to estimate the energy dissipation associated with the bending of mild steel shafts. The energy dissipated in bending the steering column shaft is $\int M d\theta$ where M is the yield moment of the cross section and θ is the bend angle.

The maximum elastic stress distribution in the shaft provided a lower bound estimate for the yield moment. An upper bound estimate was obtained by assuming a fully plastic stress profile. Table 7-1 summarizes these results in order of increasing energy dissipation.

The calculated values are comparable to the energy management capability of axially collapsible steering columns. It should be noted that energy dissipation associated with wheel, spokes, and manifold deformation is not accounted for in the above analaysis.

Table 7-1

STEERING COLUMN SHAFT DATA

Run No.	Occupant Size	Velocity (mph)	Bend Angle (Deg.)	Yield Stress Kip	Energy Dissipated in lb. Upper Bound	Energy Dissipated in lb. Lower Bound
1876	5th	35.1	3.0	74	273	161
1877	5th	40.1	14.8	75*	1364	802
1892	5th	35.3	15.0	74	1364	802
1883 1883	5th 5th (lap)	40.2	16.0	77	1514	891
1878	5th	43.1	17.5	75	1613	949
1879	95th	35.0	26.0	74	2364	1391
1898**	95th (fwd)	45.1	29.0	74	2637	1551
1880	95th	35.0	31.5	74	2864	1685
1882	95th (lap)	35.0	37.0	75	3410	2006
1893	50th	40.2	39.0	75	3594	2114
1899	50th	47.6	44.0	72	3888	2290
1896	50th (lap)	45.2	44.0	74	4001	2354
1897	50th (rear)	45.7	48.0	75	4424	2602
1881	95th	39.9	54.0	74	4910	2888
1895	50th	45.1	58.0	75	5345	3144

Yield Stress = σ radius = r = .375 in

M_e = lower bound yield moment = $\pi/4\ \sigma\ r^3$

M_p = upper bound yield moment = $4/3\ \sigma\ r^3$

* shaft not Brinnell hardness tested - average σ value used

** seat in full forward position - occupant saw significantly lower impact velocity

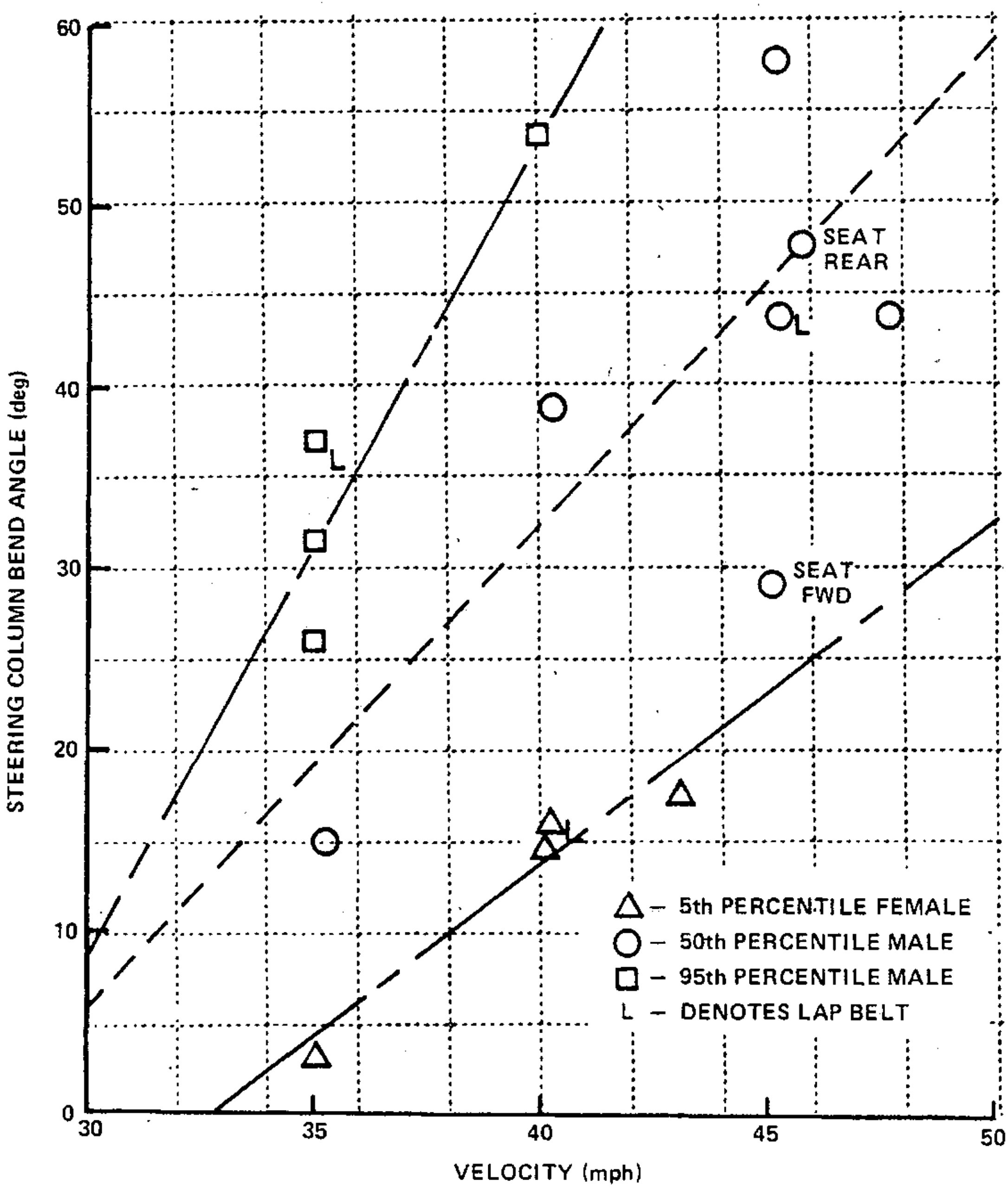


Figure 7-1 STEERING COLUMN SHAFT BENDING AS A FUNCTION OF OCCUPANT SIZE AND SLED IMPACT SPEED

7.2 Steering Wheel - Dummy Torso Crush Tests

A review of films taken during the RSV driver air bag evaluation sled testing revealed that the driver's thorax contacts the lower portion of the steering wheel rim, causing the rim to collapse. Concern over the potential for occupant injury due to this contact pointed to the need to assign a magnitude to the force associated with the collapse of the wheel rim. Two bench tests were performed to determine the maximum force level necessary to break down the wheel rim, and the corresponding torso deflection.

The driver air bag system uses a Volvo GT sport wheel which has four spokes radiating from a central hub (Figure 7-2). A manifold box mounted with four small bolts serves to tie the spokes together. When mounted on the steering column, the plane of the wheel rim is inclined 23-1/2° to the vertical plane.

Background

Films show that the steering wheel exhibits a different collapse mode for each occupant size. Prior to contact with the lower rim, the 5th percentile female dummy loads the bag pan and rim through the air bag. This increases the relative angle between the plane of the wheel and the dummy's torso. When the rim contacts the dummy, it occurs approximately two-thirds of the way up on its chest. This initial angle of contact between the steering wheel rim and the torso is approximately 55°. The female dummy continues to translate forward as the wheel rim rotates about the hub to a near vertical final orientation. The impact causes little steering column bending.

The case of the 50th percentile male dummy is characterized by a large change in wheel angle due to loading of the upper wheel through the bag. This causes the lower rim to rise three inches before it contacts the dummy's torso. Here too, the rim makes contact with the upper portion of the chest. At contact, the rim's angle to the torso is approximately 60°. The lower rim at first starts breaking down, but later its motion is dominated by the upward bending

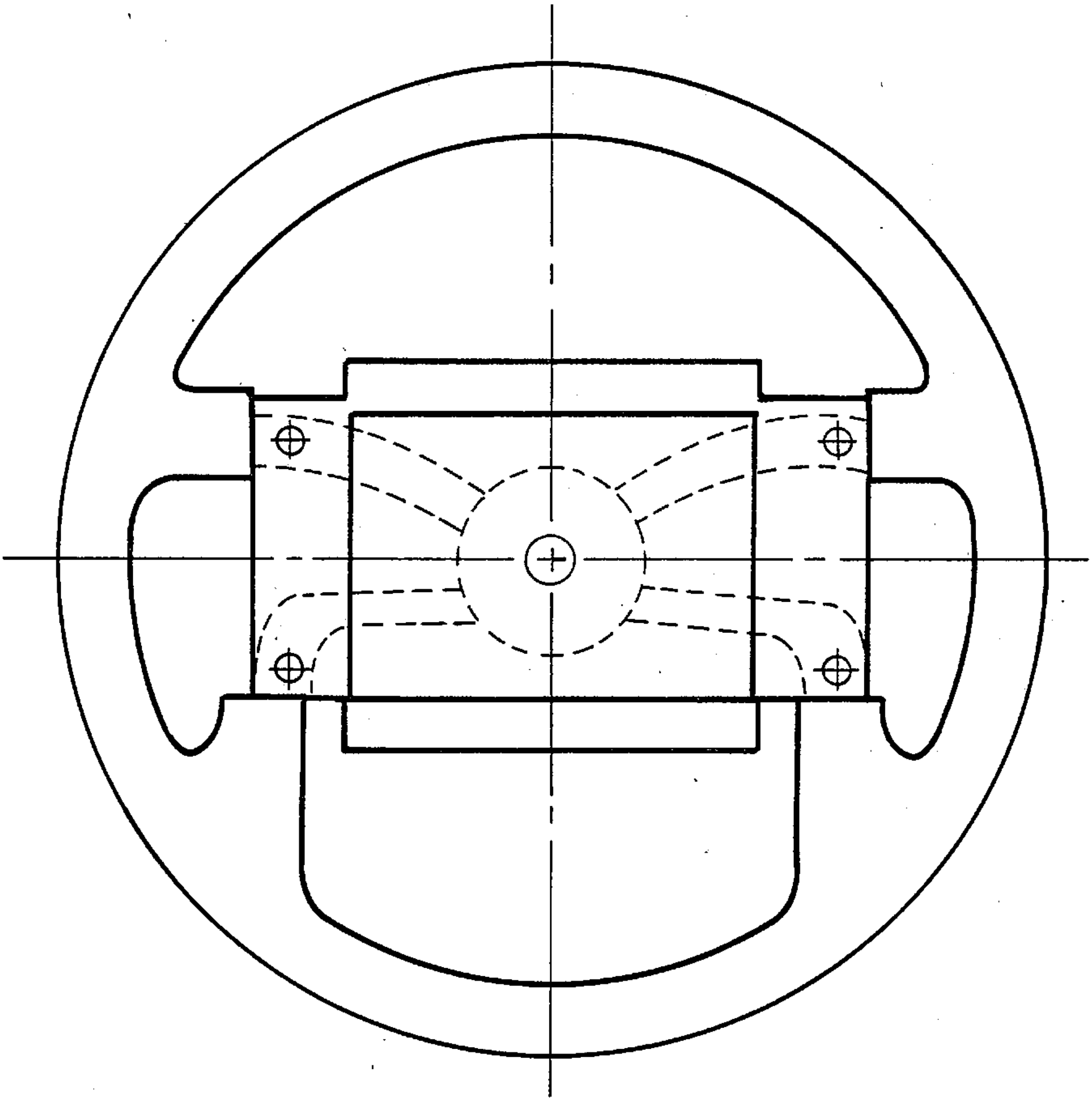


Figure 7-2 **VOLVO GT SPORT WHEEL**

of the steering column. This causes the wheel to rotate upward towards a nearly horizontal orientation.

The 95th percentile male collapses the spokes immediately upon contact with the lower rim, and proceeds to bend the steering column up. The lower half of its torso contacts the lower rim. Body rotation about the hips which begins early for the 95th percentile dummy due to the limited stroke of the knees, reduces the angle of contact to about 45°. After contact, the wheel, bag, and dummy torso move together, with the subsequent change in steering wheel angle corresponding to the change in body angle.

Crush Tests

Two crush tests were performed which represented the most critical conditions observed in the sled runs. Both wheels were oriented at a 60° angle with respect to the dummy torso. The wheel in the first test made contact at a point nine inches down from the top of the thorax (see Figure 7-3). The wheel in the second test made contact 11-1/2 inches down from the top of the torso.

The tests were conducted on an arbor drill press, for which the table height could be adjusted. A Volvo GT sport wheel was mounted on a stub shaft which had been bent 30°. A 50th percentile male dummy thorax with three load cells attached to it was mounted on a stand angled 30° to the horizontal, thereby resulting in a 60° contact angle between wheel rim and dummy torso.

Measurements were taken for five points on the rim, manifold box, and hub. These coordinates as well as the load cell readings were recorded as the table was moved up in half-inch increments. Figure 7-4 shows the pre- and post-test configuration for wheel (1) while Figure 7-5 shows wheel (2) in various stages of crush.

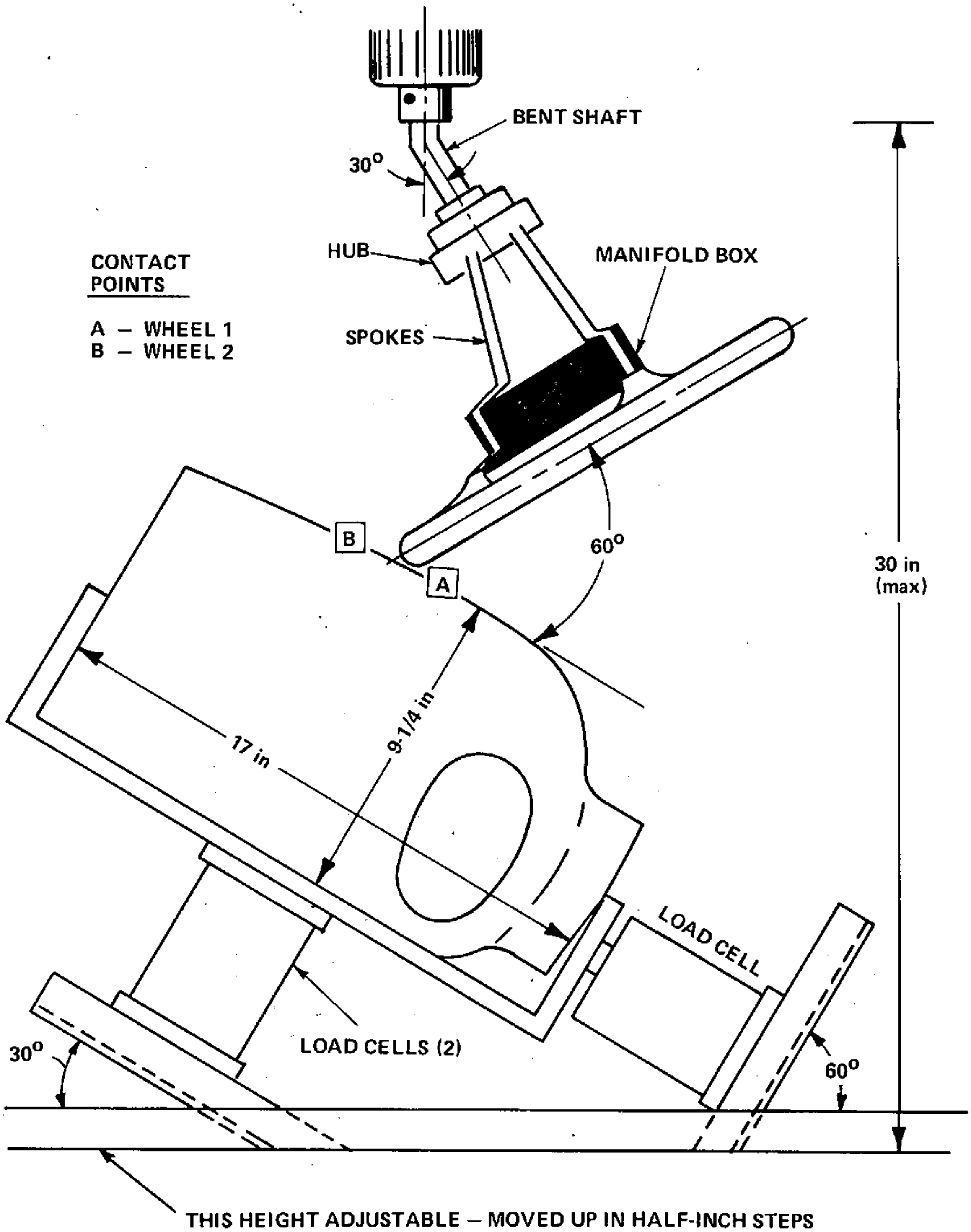


Figure 7-3 **TEST SET-UP**

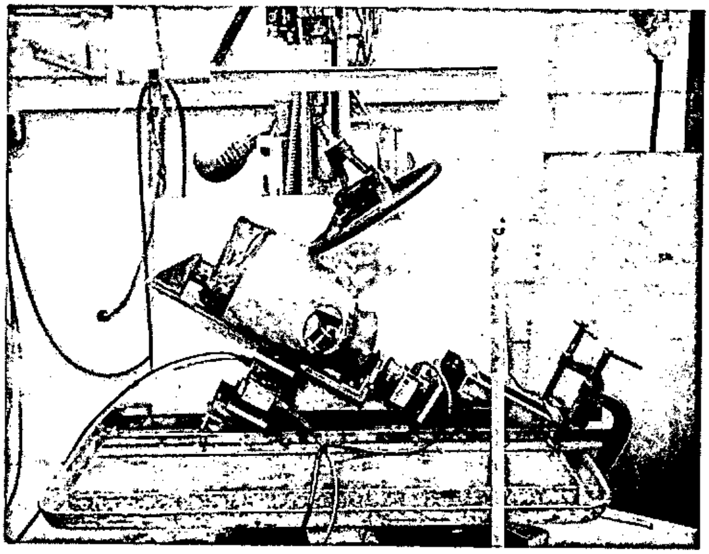


Figure 7-4a WHEEL (1) PRE TEST SET UP

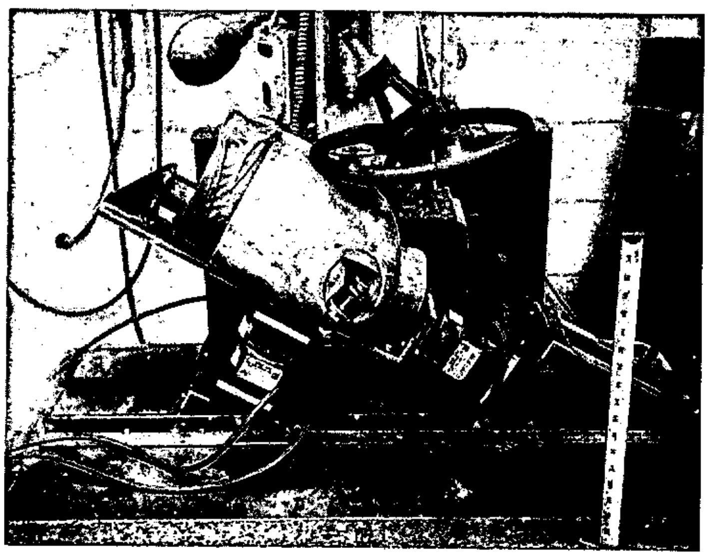
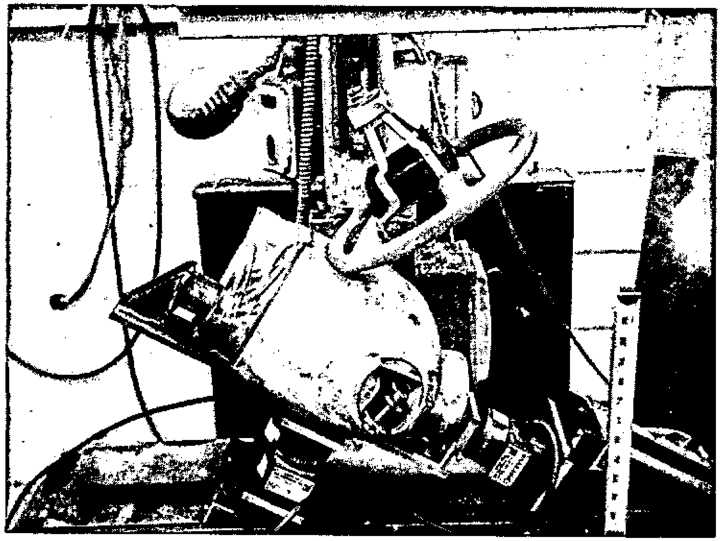
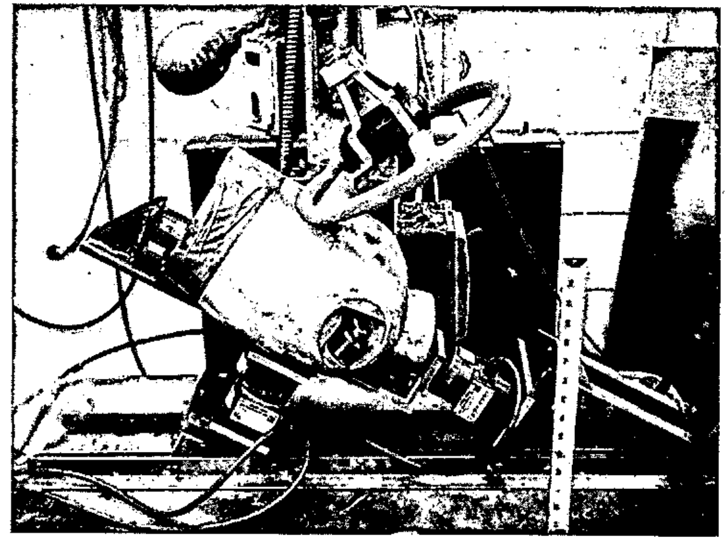


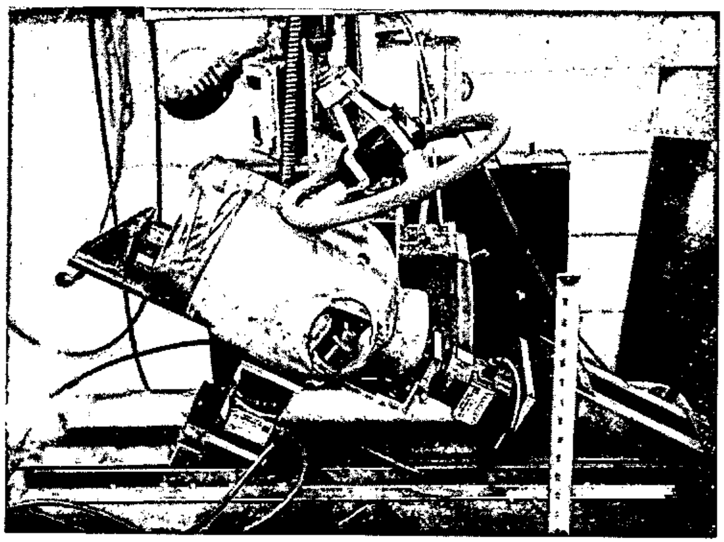
Figure 7-4b WHEEL (1) POST-TEST



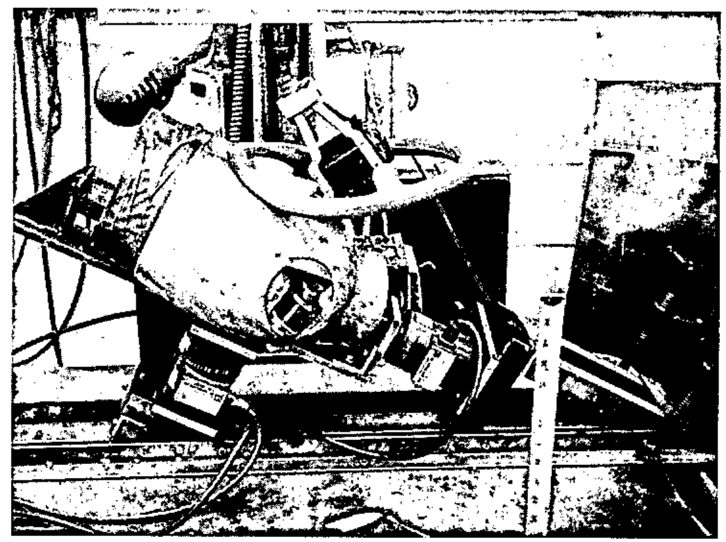
FORCE: 250 lbs
PENETRATION: 3/4 in



FORCE: 750 lbs
PENETRATION: l-1/2 in



FORCE: 650 lbs
PENETRATION: 1-3/8 in



FORCE: 700 lbs
PENETRATION: 1-1/8 in

Figure 7-5 **WHEEL (2) VARIOUS STAGES OF CRUSH**

A maximum dummy torso penetration of 1-1/2 inches, measured normal to the torso plane, was obtained in Test 1. The maximum normal force was 628 pounds (see Figure 7-6). An illustration of the deformed wheel is presented in Figure 7-7. In the test with wheel (2), 1-5/8 inches of penetration were observed with a corresponding normal force of 801 pounds (see Figure 7-8). The manifold box which tied the wheel spokes together did not experience significant deformation in either case.

Bearing surface data were not taken for wheel (1). Wheel (2) had a maximum contact area of approximately six square inches. This would result in a maximum mean pressure of over 100 psi.

Although this pressure value may be high with regard to injury tolerance, from viewing the films of the sled tests it seems safe to reason that the loads transmitted through the air bag aid the torso in breaking down the rim. This would suggest that the pressure values obtained here represent an upper bound. With regard to chest deflection or penetration, an important parameter for survival, these values fell within acceptable levels.

In conclusion, it is believed that the results of the static tests reflect the maximum forces to the torso involved in breaking down the rim. In the dynamic case, the various eccentricities of loading are likely to supply the torso/wheel interaction with a less aggressive collapse mode. Nevertheless, the relatively small amount of surface area of the lower rim does indicate relatively high contact pressures, and consideration of approaches to minimize this phenomenon is warranted.

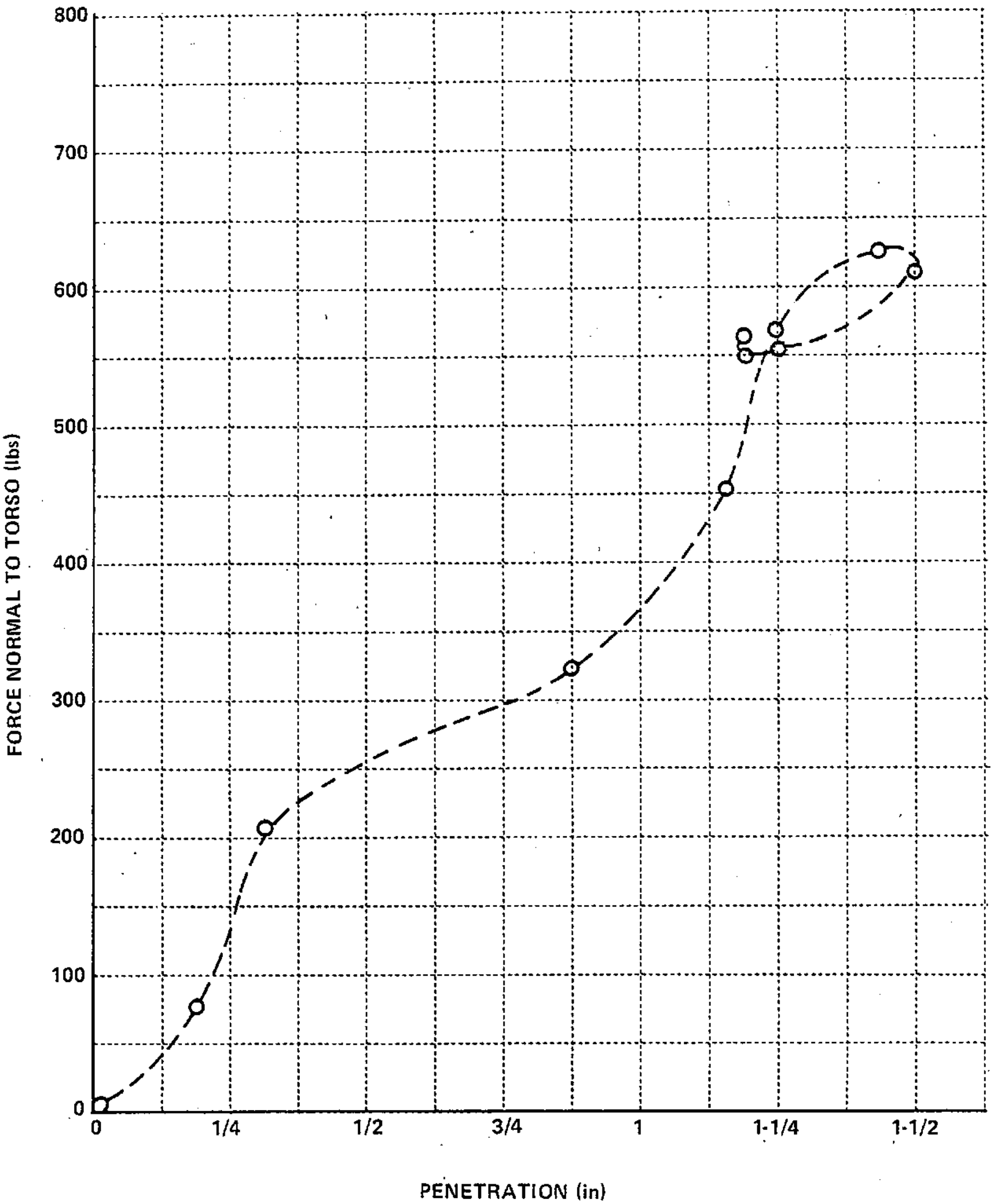


Figure 7-6 WHEEL (1)

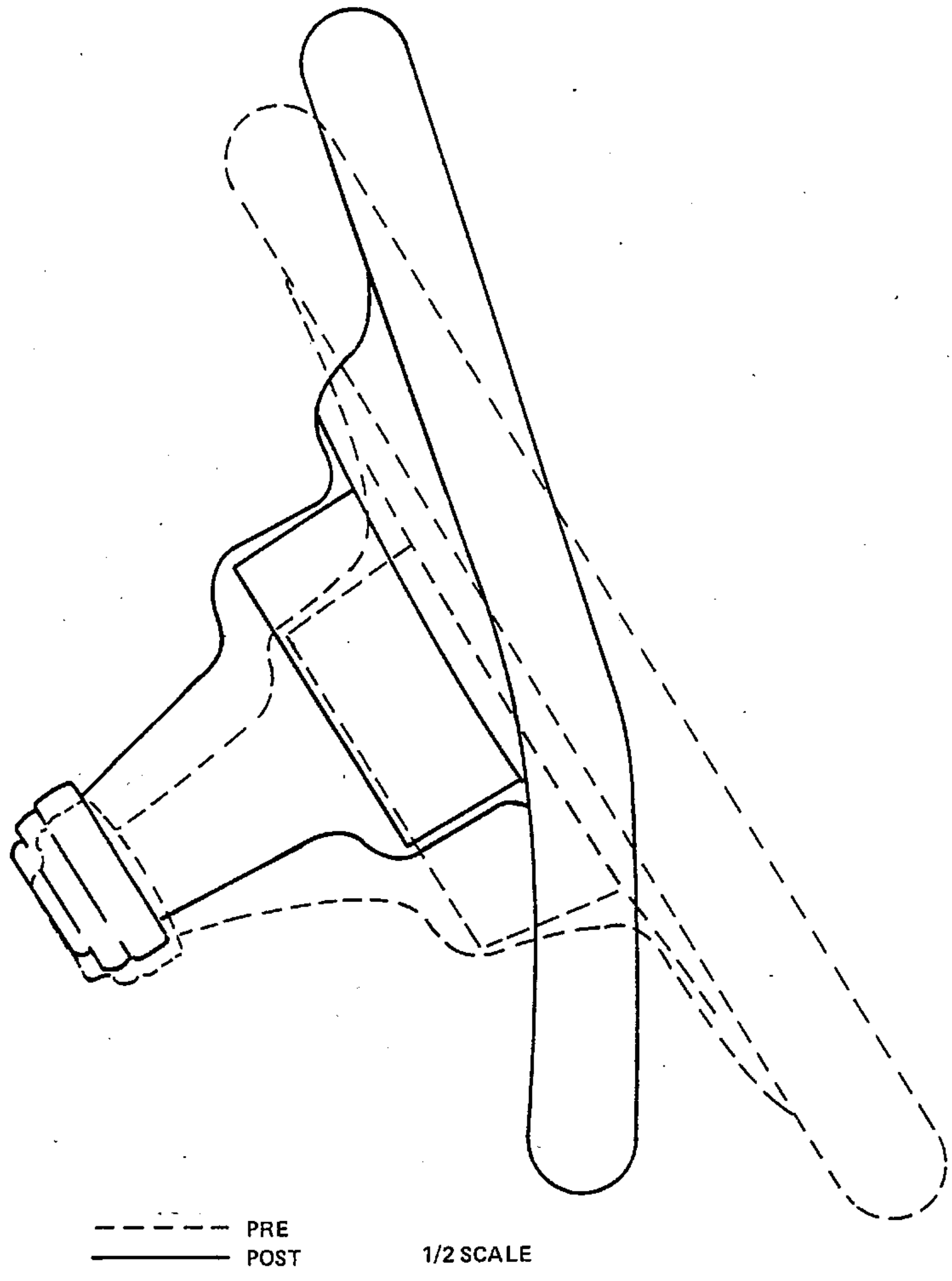


Figure 7-7 WHEEL (1) PRE- AND POST-TEST

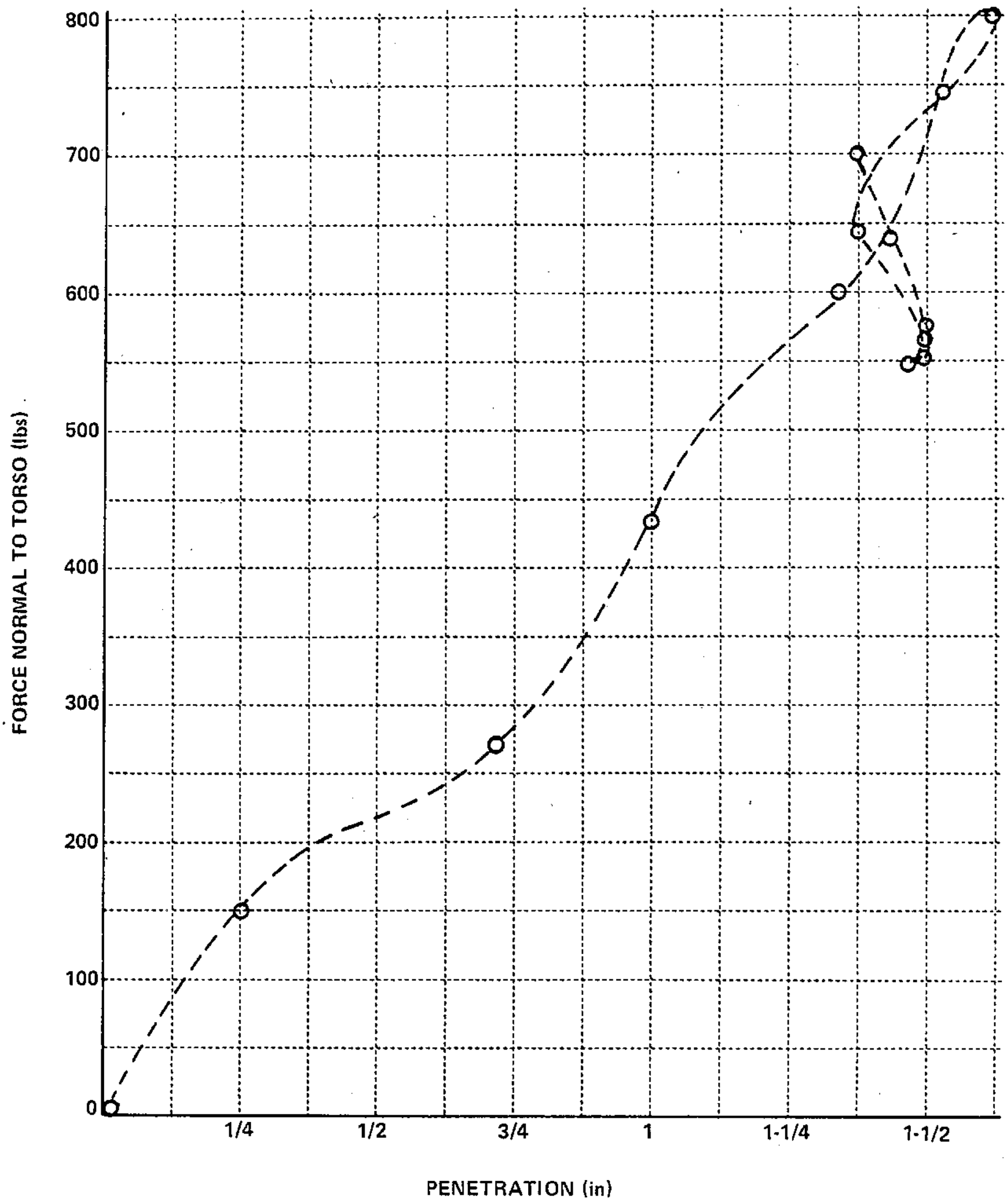


Figure 7-8 WHEEL (2)

8.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of the experimental development program performed using a postulated 40 g maximum compartment deceleration pulse at 45 mph for the RSV, the following conclusions are drawn:

8.1 Conclusions

(1) The major goal of the RSV driver air bag development program was accomplished. An integrated, producible driver air bag restraint system was designed for the Calspan/Chrysler RSV.

(2) A critical evaluation of the range of capabilities for the system has been made. Occupant size performance as a function of velocity as well as off-design conditions of lap belt use and seat position have been examined.

(3) For the 50th percentile male driver, acceptable injury responses were obtained at impact speeds in excess for 45 mph for the following conditions.

- normally seated
- normally seated with lap belt
- front seat in full forward position
- front seat in full rearward position
- +12°, +20°, and -20° sled angle exposures

(4) Acceptable injury criteria were recorded for the 5th percentile female driver for the normally seated and lap belt conditions at impact speeds in excess of 40 mph.

(5) For the 95th percentile male acceptable chest and femur results were obtained through the 40 mph speed range. Insufficient head clearance in the base vehicle interior design precluded satisfaction of the head injury criteria.

(6) Some specific areas where the system can be improved were defined by this evaluation process. In particular,

- the driver chest contacts the lower steering wheel rim during the restraint process
- the lower torso restraint for the full rearward-seated 50th percentile driver is marginal. The 50th percentile driver came off the seat in the 45 mph test with that seat configuration.

8.2 Recommendations

The major deficiency associated with the driver air bag restraint system is the occurrence of chest contact with the lower steering wheel rim. It is the author's opinion that the initial system/occupant geometry is the primary cause. When deployed, the air bag fills symmetrically about the steering wheel plane which is initially -23-1/2° from vertical. The driver torso translates at an angle, +26-1/2°, until sufficient lower torso restraint begins to induce rotation. Thus the driver commences loading of the air bag at an angle of approximately 50°. This non-normal loading tends to push up the bag and expose the lower wheel rim to contact with the chest. Thus the primary remedy is to redesign the base vehicle steering system such that a significantly lower column angle could be employed.

An alternative means of reducing the wheel rim interaction problem would be to increase the lower torso restraint. This would induce more upper torso rotation and would minimize the forward displacement of the lower chest. These features would cause the driver to load the air bag in a manner more normal to the wheel plane and would reduce the possible contact with the wheel rim.

It is suggested that additional effort be expended to investigate the severity of chest-to-wheel rim contact and to determine if the above recommendat can in fact alleviate the problem.